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CHARACTERIZATION OF EMISSIONS AND FUEL ECONOMY OF IN-USE DIESEL AUTOMOBILES

by

Richard E. Gibbs
James D. Hyde
Robert A. Whitby
New York State
Department of Environmental Conservation
Albany, New York 12233

Delip R. Choudhury
New York State
Department of Health
Albany, New York 12201

EPA Grant R805934

Project Officer

Peter Gabele
Emissions Measurement and Characterization Division
Environmental Sciences Research Laboratory
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

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16. ABSTRACT

Exhaust emissions from twenty 1977-1980 in-use light-duty diesel vehicles were measured to determine the effects of driving cycle, mileage accumulation, and test conditions. Hydrocarbons, CO, CO_2, NO_x and particulates were measured for the FTP, HFET, CFDS, NYCC, 50 mph cruise(50C) and idle cycles. Particulate extract was tested for mutagenicity by the Ames method. Selected composite extracts were chemically analyzed and bioassayed. Emissions (g/mi) and fuel consumption generally increased in order 50C < HFET < CFDS < FTP < NYCC. GM vehicles generally had higher emissions and more sensitivity to driving cycle than the Mercedes-Benz and VW vehicles. Particulate extract emissions were not generally cycle dependent. NO_x emissions decreased with mileage accumulation while other emissions increased or were unaffected. Fuel economy was determined by the carbon balance method, by fuel meters and by fueling records. Over-the-road fuel economy was always lower than carbon balance fuel economy. A new method for real-time particulate measurement is described using a Tapered Element Oscillating Microbalance (TEOM). The TEOM mass was within 10% of the gravimetric mass with a response time of 8-15s. Effects of driving cycle sequence, dilution tunnel, sub-FTP temperatures and mutagenic artifact formation were examined. Bulk extract samples were fractionated and analyzed by GC, GC/MS and HPLC/UV. The acidic fraction had the highest specific activity, but most total activity was in the neutral fraction which contained fluorenones and oxy-PAH's.

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PREFACE

Within the New York State Department of Environmental Conservation, the Division of Air is charged with the responsibility of monitoring and regulating atmospheric pollutants in the public interest to protect human health and environmental quality. The scope of this task includes the investigation of specific regulated and unregulated emission sources in order to assess environmental impacts. Diesel powered automobiles are rapidly increasing as a percentage of the total vehicle population and pose potential health and environmental quality risks which must be understood and considered in air quality management.

The expertise in automotive emissions technology of the Automotive Emissions Laboratory was employed to undertake this study of fuel economy and emissions measurement from in-use diesel automobiles in order to determine typical emission values and the effects of mileage accumulation on emissions. The results of this study represent a valuable contribution to the development of air programs for the protection of public health and the environment.

H. Hovey
Director, Division of Air

ABSTRACT

A New York State research study on exhaust emissions tested twenty 1977-1980 light duty diesel vehicles repeatedly over a two-year mileage accumulation period. Measured emission parameters were hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides and particulates from the FTP, HFET, CFDS, NYCC, idle and 50 mph driving cycles. Individual particulate samples were Soxhlet extracted with dichloromethane to partition the particulate into extract (soluble) and residue (insoluble). The extracts were tested for mutagenicity by the Ames *Salmonella typhimurium*/microsome method. Selected composite particulate samples were also collected for detailed chemical analysis and subsequent bioassay.

Emissions (g/mi) by driving cycle generally increased in the order 50C < HFET < CFDS < FTP < NYCC and fuel economy decreased in that order. Vehicles in the General Motors group generally had higher emissions than the Mercedes-Benz and Volkswagen groups and were more sensitive to driving cycle. Particulate extract emissions showed very little cycle dependence but residue emissions were very cycle dependent. In general, emissions were unaffected by, or increased with, mileage accumulation with the exception of NO_x, which decreased.

Dynamometer fuel economy was determined by the carbon balance method. Over-the-road fuel economy was determined by using fuel meters and vehicle odometers and taking vehicle fueling records. Dynamometer fuel economy was always higher than over-the-road fuel economy. The FTP best approximated average over-the-road fuel economy.

A new method for the real-time measurement of diluted diesel particulate by a Tapered Element Oscillating Microbalance (TEOM) is presented. The mean ratio of TEOM results to those obtained by the FTP method using 47 mm filters was 0.96 (CV = 13%). Data for limited vehicle testing are presented.

Results of special experiments are presented for the effects of driving cycle sequence on emissions, of the dilution tunnel on particulate measurement and mutagenic activity, and of cold ambient temperatures. Particulate and extract were re-exposed to diluted exhaust to determine the exposure-time effects on mutagenic activity.

A discussion is presented of work conducted to isolate, identify and quantify the chemical substances responsible for the mutagenicity of the extract. Bulk samples of extract were fractionated and analyzed by GC, GC/MS, and HPLC/UV. The acidic fraction had the highest specific activity, while most of the total activity was in the neutral fraction due to its greater mass. Four-ring PAH's and their alkyl-substituted homologues were predominant. Ketone, quinone, carboxaldehyde and hydroxy derivatives and their alkyl homologues were characterized. The single largest family of compounds detected was 9-fluorenone and its C_1-C_4 alkyl homologues.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS OF UNITS

cfm	cubic feet per minute
cm	centimeter
g	gram
in	inch
Kg	kilogram
Kw	kilowatt
L, l	liter
lb	pound
m	meter
mi	mile
min	minute
ml	milliliter
mm	millimeter
mph	miles per hour
sec	second
µg	microgram

ABBREVIATIONS OF THINGS

A	Automatic
AEL	Automotive Emissions Lab
BaP	benzo(a)pyrene
C	carbon
CFDS	Congested Freeway Driving Schedule
CI	chemical ionization
CO	carbon monoxide
CV	coefficient of variation
CVS	Constant Volume Sampler
DCM	dichloromethane
DISP	displacement
dm	quantity of mass
DMSO	dimethylsulfoxide
DPE	diesel particulate extract
EI	electron impact
EPA/RTP	Environmental Protection Agency, Research Triangle Park
EXT	extract
f	frequency
FTP	Federal Test Procedure

GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
GM	General Motors
HC	hydrocarbon (by HFID)
HFET	Highway Fuel Economy Test
HFID	hot flame ionization detector
Hg	mercury
HP	horsepower
HPLC	high pressure liquid chromatography
IDLE	idle in neutral gear
I.W.	inertial weight
K	kilo, thousand
KgF	kilogram fuel
M	manual
MB, M-B	Mercedes-Benz
MIDPT	midpoint
MPG	miles per gallon
MPH	miles per hour
MS	mass spectroscopy
N	number of items
NBS	National Bureau of Standards
NO_x	nitrogen oxides (as nitrogen dioxide)
NQNO	4-nitroquinoline-N-oxide
NVHC	non-volatile hydrocarbon
NYCC	New York City cycle
OLDS	Oldsmobile
oxy-	oxygenated
P, Part, PT	particulate
PAH	polynuclear aromatic hydrocarbons
PDP	positive displacement pump
RES	residue
REV	revertant bacterial colonies
SOF	soluble organic fraction
STD DEV	standard deviation
S9	liver homogenate fraction
TA98, TA100	bacterial tester strains
TEOM	Tapered Element Oscillating Microbalance
UV	ultraviolet
VW	Volkswagen
2-NF	2-nitrofluorene
50C	50 mph steady cruise

SYMBOLS

°C	degree Celsius (centigrade)
n	number of items in group
R^2	correlation coefficient
$\bar{x}$	mean (arithmetic)
σ	standard deviation
%V	percent emission change per 1000 miles
(-)	without S9

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PROJECT COLLABORATION

A project of this scale succeeds only by the cooperative effort and sharing of ideas from a diverse group of dedicated people. Project accomplishments are here properly attributed to a teamwork approach by the following project members:

Name	Organization	Area
Richard Gibbs	Environmental Conservation	Project Leader
James Hyde	Environmental Conservation	Lab Data/Project Data Analysis
Robert Whitby	Environmental Conservation	Computer Analysis/TEOM
Robert Johnson	Environmental Conservation	Vehicle Testing/TEOM
Paul Werner	Environmental Conservation	Vehicle Testing
Ben Hill	Environmental Conservation	Computer Analysis
Stan Byer	Environmental Conservation	Project Logistics
Tom Hoffman	Environmental Conservation	Chemical Laboratory
Delip Choudhury	Health Department/Toxicology	Extract Chemical Analysis
Brian Bush	Health Department/Toxicology	Extract Chemical Analysis
Charles Doudney	Health Dept./Env. Health	Bioassay
Mary Franke	Health Dept./Env. Health	Bioassay
Charlie Rinaldi	Health Dept./Env. Health	Bioassay

A vast array of organizational support staff in both participating New York State Departments played a major role in making the work possible.

SECTION 1

INTRODUCTION

The control of mobile source emissions to achieve air pollution goals has been one of the significant technical/social challenges of recent years. The multitude and diversity of these emission sources, the relative difficulty of reducing emissions of some pollutants from in-service vehicles and the co-existence of vehicles and people in urban settings all have impacted approaches taken to minimize the effect of mobile source emissions on air quality.

Mobile source emission programs began essentially as a gasoline-powered vehicle emissions control program. These efforts now must not only adapt to the increased diversity of gasoline combustion technologies, but must also address the presence of a significant diesel-powered component in the vehicle population. In New York State the number of diesel-powered light-duty vehicles in 1975 was a mere 3,265, but by 1980 this number had increased at an average annual geometric rate of about 68% to become 44,122, an increase from 0.05% to 0.64% of this total vehicle population in a five year period (1). This increase has occurred during a period of sales depression in the general new-car market. The significantly different emissions of diesels, coupled with their recent accelerated penetration into all vehicle weight classes, thus represents an emerging factor in the mobile source picture that demands adjustment to the process of developing policies to optimize the nation's transportation/energy/air quality balance.

How many diesels will there be? What will be their emissions impact? How will diesel related emission technology evolve? Should diesels continue to be exempt from inspection/maintenance requirements? What are the composite HC, CO, NO_x, and particulate impacts on ambient air quality levels for various possible future diesel scenarios? In concert with other emissions, what visibility and health impacts should be expected?

These are not all the questions, but they typify the magnitude and uncertainty of the impact that present events will make for some future time, a time when little can be done but accept the vehicles and their effects in retrospect. Thus the need to develop a technical viewpoint to aid in the identification of important diesel issues was an underlying motivation behind this joint New York State/Environmental Protection Agency research study described in this project report.

The New York State diesel study grew from the need for comprehensive emissions test data on in-use diesel automobiles. Comprehensive, in this context, refers to mass emissions testing for HC, CO, NO_x, fuel economy, particulate by the identical tests used by vehicle manufacturers to certify new vehicles - the Federal Test Procedure (FTP), and additional investigations regarding the characteristics of the emitted particulate. Other types of vehicle operation were included to obtain the same types of emission data for conditions ranging from New York City driving to highway operation. Thus tailpipe particulate was measured for various vehicle types, vehicle mileage/ages, commonly used fuel and lubricating oils, and vehicle operating modes. Particulate samples collected for each of the many combinations of parameters mentioned were individually solvent extracted to determine the "extractible" and "residue" make-up of the total particulate. The extracts (or soluble organic fractions) were then subjected to a bioassay screening test to determine the relative mutagenic potency as functions of many of the test parameters. All data were entered into a computer data base from which analyses, correlations and tabulations were performed.

A parallel effort to the in-use vehicle study was directed toward chemical identification of the mutagenic species present in the extract samples. The chemistry of the extracts is analogous in complexity to cigarette smoke, and the mutagenic activity is not attributable to the major components. Thus chemical identification of the mutagenic species is a difficult task and only a few select samples were extensively examined. Three project vehicles (Oldsmobile, Volkswagen, and Mercedes-Benz) were operated on the dynamometer for a total of 50 days to collect sufficient particulate (50-100 g of particulate each) to obtain, after solvent extraction, the quantity of extract needed for chemical characterization work.

The in-use vehicle regulated emissions testing, experimental developments in obtaining particulate emissions data, chemical characterization of large samples, bioassay results from both in-use vehicle tests and large particulate samples, and analysis of project data base results all are significant aspects of this study. This report summarizes the study and its findings shortly after completion of the data collection effort. Further examination of the data base, chemical analyses on the archive of project extract samples, etc. may well extend the application of these data. The project was not intended to directly address the policy type of questions listed above, but was designed to contribute technically to their understanding.

The analyses and discussions in this report use only a portion of the data collected in this project. Many other worthwhile analyses could be made but were not made due to time restraints. In general the analysis has been limited to Phase 3 data (controlled conditions) and in many cases to only FTP Phase 3 data (e.g. in the mileage accumulation section). In many cases a preliminary analysis of the data showed extension to another phase or to other cycles would not significantly contribute to the results of this study. Vehicle averages for 12 parameters for Phase 1 and Phase 3 are given in Appendix A. In addition, this appendix includes data for six parameters from each of the three individual bags of the FTP. These data are not discussed in the report.

Samples of all fuels used in the project were extensively analyzed. Although many instances were found in which fuel effects were apparent, no detailed analysis of fuel composition effects on emission parameters have been attempted.

Almost all Ames data discussed represent strain TA98 testing without activation although many samples were analyzed with activation and with other strains. The bioactivity-emissions correlation study lumped all Phases together in order to achieve the largest possible data base. The study was limited, however, to determination of linear correlation coefficients. Non-linear or multivariable analysis of the data base must be left for future work.

SECTION 2

CONCLUSIONS

The New York State research team investigated the emission characteristics of light-duty diesel passenger vehicles typical of the 1978-1979 period when the study began. Many results apply to diesel emissions in general; but others are specific to this vintage vehicle and should not be extrapolated to other cases. This section is composed of those general conclusions felt to relate to the diesel emission field, and specific conclusions from the experimental work performed.

GENERAL CONCLUSIONS

Particulate, CO, HC, and NO_x emissions (g/mi) increased significantly for New York City driving conditions relative to the certification driving cycle for the Federal Test Procedure.

Particulate emissions for some vehicles exhibited significant increases with mileage accumulation whereas other vehicles remained relatively constant (no deterioration) throughout the period of the project.

When significant mileage accumulation increases in particulate mass emissions were observed, the increase was predominantly due to increases in the extractible (not residue) portion of the particulate.

Total hydrocarbon emissions are composed of both gas and condensed (as part of particulate) phase material. The particulate-bound portion was 20-60% of the total hydrocarbon emission with the 50C having the highest values and the IDLE the lowest. Driving cycle, vehicle type, and vehicle age accounted for the variation range.

Measurement of diesel engine particulate mass emissions in real-time is now a possibility. This development impacts several areas of diesel emissions understanding previously limited by use of long-time filter sampling. Some areas where this capability can be expected to have application: 1) focusing engine development work on emission prone modes, 2) correlation of vehicle operation characteristics with certification test cycles, and 3) developement of short vehicle tests suitable for on-road vehicle emissions projections.

The bioassay potency of particulate extracts (by Ames tester strain TA98 without activation) exhibited considerable variation with project variables, but was positive for all samples (over 1100) analyzed.

Direct correlation of bioassay activity with specific vehicle-test parameters was not achieved, but a complete examination of the data base for possible correlations has not been performed.

For all General Motors vehicles as a group, Ames test activity correlated very significantly with the residue (and not with the extractible) portion of the particulate samples. This finding was true to a lesser extent for other vehicle groups but was emphasized in the General Motors case by the higher extractible content of the particulate.

Mileage accumulation plots of % extractible and extract bioassay activity (revertants/ μg extract) showed these two parameters to be inversely related for virtually all vehicles.

The solvent extractible portion of the particulate is mainly derived from absorption of hydrocarbons and hydrocarbon derived species onto a carbon core formed in the combustion process. However, some extractible is certainly formed in the combustion chamber along with the carbon core and this material may contain most of the direct acting mutagens. The bulk of the extract is primarily a diluting medium for the small amount of biologically active material.

The polynuclear aromatic hydrocarbon (PAH) emission products cannot account for the observed direct acting mutagenicity of extracts, but the nitro-PAH and oxy-PAH species likely combine to account for much of the Ames activity.

The oxy-PAH species present in typical samples from this project have been characterized in new levels of detail, and thus contribute to the advancement of a chemical basis for understanding diesel emissions. The reaction processes, whether in combustion, emission, sampling, extraction, bioassay or atmospheric zones, leading to nitro-PAH and oxy-PAH should be active topics for future diesel research .

Comparisons of over-the-road fuel economy to laboratory carbon balance fuel economy showed the laboratory measure to be approximately 15-20% above the over-the-road case at corresponding vehicle average speeds. Road grade, temperature, snow, wind, etc. can easily account for this increment.

The FTP laboratory value corresponded most closely to the over-the-road value even though the average vehicle speed in the FTP is much lower than for over-the-road operation. This speed discrepancy thus approximately caused the same fuel economy effect as the real-world factors not included in the laboratory test.

SPECIFIC CONCLUSIONS

Driving Cycle Effects

(1) For Car #5, a 1979 Oldsmobile Cutlass Cruiser with 5.7 L engine, it was found that:

a) the cycle driven prior to the FTP cold soak had no effect on gaseous emissions and had little effect on particulate emissions except when that cycle was an IDLE;

b) previously driven IDLEs increased the particulate emissions of subsequent driven cycles but did not affect gaseous emissions;

c) gaseous measurements were not affected by the previously driven cycles;

d) gaseous measurements when repeated on separate days had a coefficient of variation, CV, of less than 5% except for the IDLE where the CV's were several times larger;

e) the fuel economy of a cycle increases with increased repetition of that cycle during a day.

(2) For all vehicle groups, driving cycles affect emissions in a consistent manner. The general trend of decreasing emissions was NYCC > FTP > CFDS > HFET > 50C.

(3) The General Motors group had emissions which were much more sensitive to driving cycles than were the Volkswagen and Mercedes-Benz groups.

(4) With the exception of residue for the HFET and 50C, the General Motors group had greater g/mi emissions than the Volkswagen or Mercedes-Benz groups.

(5) Cycle variations of particulate, g/mi, were principally due to variations in residue mass for all vehicle groups.

(6) Residue, g/mi, was very cycle dependent for the General Motors group but only slightly cycle dependent for Volkswagen and Mercedes-Benz groups. It increased in the order 50C < HFET < CFDS < FTP < NYCC.

(7) Extract, g/mi, showed very little cycle dependence except for a very large increase for the NYCC for all vehicle groups. The CFDS, HFET and 50C had similar extract, g/mi, emissions with a slight increase (0.02 g/mi overall) in the order CFDS < HFET < 50C for all vehicle groups.

(8) Extract, %, showed no cycle variations for the Mercedes-Benz group, few variations for the Volkswagen group and strong cycle dependence for General Motors group.

(9) The HFET and 50C had very similar gaseous emissions except for hydrocarbons from the General Motors group.

Mileage Accumulation Effects

(1) FTP particulate emissions did not show a mileage related deterioration (increase) for the Volkswagen group and the Mercedes-Benz groups, but showed a large deterioration for the General Motors group due to a large increase in extractible emissions.

(2) FTP hydrocarbon emissions did not show a mileage related deterioration for the Volkswagen and Mercedes-Benz groups, but showed a deterioration for the General Motors group.

(3) FTP carbon monoxide emissions showed a deterioration of the General Motors and Volkswagen groups but not for Mercedes-Benz group.

(4) FTP nitrogen oxides emissions showed a decrease with accumulated mileage for the General Motors and Mercedes-Benz groups but no trend for the Volkswagen group.

Fuel Economy

(1) Over-the-road fuel economy as measured by underhood meters between vehicle tests was approximately 15-20% less than laboratory carbon-balance fuel economy at comparable average vehicle speeds.

(2) Over-the-road fuel economy, while of higher average vehicle speed than the FTP, was most closely approximated by FTP economy.

(3) Laboratory fuel economy increased with increased average speed of the driving cycle, i.e. NYCC <FTP <CFDS <HFET <50C.

(4) Laboratory fuel economy data normalized to vehicle test inertia (ton-mile/gallon) were generally less than 10% apart for the vehicle groups for all test cycles except the NYCC.

(5) Fuel economy as ton-mile/gallon for the NYCC showed the General Motors group to be about 30% lower than the Volkswagen and Mercedes-Benz groups. The General Motors group weight-specific fuel economy improved at high speeds relative to the Volkswagen and Mercedes-Benz group values, and exceeds the Volkswagen group value by a small amount for the 50C.

Ames Characterization

(1) No overall definitive effect of fuel/lubricating oil could be established between phases but significant differences were noted for several cases.

(2) When significant Ames activity changes where observed between phases, the changes were generally consistent for all test cycles.

(3) No general mileage accumulation trend for Ames activity expressed in per mile units was observed. Large changes, both positive and negative, were observed with accumulated mileage.

(4) Ames activity generally increased in the order GM < MB < VW for all test cycles and all methods of expressing activity.

(5) The Ames activity of the NYCC extract was generally lower than that for other driven test cycles for all vehicle groups.

(6) An inverse relationship between % extractible and Ames specific activity (revertants/μg extract) with accumulated mileage was observed for most of the project vehicles.

(7) Graphical representation of vehicle group average bioactivity (revertants/mile), extract (grams/mile), and residue (grams/mile) over various driving schedules employed in this study suggests that bioactivity variation more closely follows residue variation than extract variation when the data are normalized to the FTP schedule values.

(8) Linear correlation analysis of emission and bioactivity parameter data did not discover highly correlated parameter relationships which were consistent for all vehicle types and driving schedules. Linear correlations among emission and bio-

activity parameters were generally very weak although often statistically significant. A certain degree of consistency in the sign of the linear correlation coefficient was observed over most vehicle types and driving schedules for certain parameter pairs. Revertants per μg extract was the bioactivity parameter which most frequently yielded a statistically significant correlation coefficient. The correlation coefficient for revertants/ μg extract and emissions were typically negative for extract emission parameters and positive for residue emission parameters.

Real-Time Particulate Measurement

(1) The first successful test of a prototype real-time diesel particulate mass-measurement instrument was achieved. This instrument, a Tapered Element Oscillating Microbalance (TEOM) was used in dilution tunnel sampling and demonstrated correspondence with standard filter collection while providing real-time resolution of particulate emissions.

(2) The time resolution achieved during this test of the TEOM was 8 seconds, and with further work this time constant may be decreased.

(3) TEOM data may be obtained either directly from the instrument microprocessor or from data storage on a host computer. When the latter method is employed, the TEOM raw data signal may be reanalyzed by user defined algorithms to obtain new information from existing test data.

Fuel Specific Emissions

(1) Fuel specific particulate (g/kg Fuel) was fairly constant for all driving cycles for Mercedes ($\sim$ 3.5-4.0 g/kg Fuel).

(2) Fuel specific particulate for Volkswagen group showed an increasing trend with higher speed cycles (3.5-5 g/kg Fuel); whereas General Motors group vehicles showed a decreasing trend with higher speed cycles (5.5-4 g/kg Fuel).

(3) The main variations in fuel specific emissions were due to changes in residue and not extract emissions.

Chemical Characterization of Extract

(1) The acidic fraction of the extract had the highest specific activity but most of the total activity was in the neutral fraction due to its greater mass.

(2) Four-ring PAH's and their alkyl-substituted homologues were the predominant constituents.

(3) 9-fluorenone and its C_1-C_4 alkyl homologues was the single largest family of compounds.

SECTION 3

EXPERIMENTAL APPROACH

INTRODUCTION

The technical literature contains numerous reports of diesel emissions investigations, and no attempt will be made here to provide a complete literature review. The bulk of literature on this subject is found in the publications of the Society of Automotive Engineers (SAE). Collections of SAE papers on diesel emissions are available (2-10). Works are available on measurement of emissions (11-15), health effects (16-24) and policy decision (25-27). Some historical perspective will be given to provide the reader a sense of the context at the time this study was undertaken, and the references listed for this section provide access to the general body of diesel emissions literature.

Prior to the mid-1970's, diesel combustion was viewed primarily in relation to heavy-duty vehicles. Research reports on emissions for these types of engines dealt with particulate emission measurement, emission effects of fuel properties, chemical characterization of extracts, particulate size data, odor characterization, and opacity measurements. Some detailed chemical characterization work was undertaken at this time, but the emphasis tended to be on known toxic or carcinogenic species such as benzo(a)pyrene. Beginning in the mid-1970's there was increased emphasis on light-duty diesel emissions from passenger cars as well as continued heavy-duty characterization studies, measurement technique development, and physical characterization.

The first reports of positive bioassay indications from diesel particulate extract by the Ames test were paralleled by projections of the increasing use of diesel engines for light-duty vehicles. These combined factors directed much research into the complex organic mixtures obtained from solvent extraction of particulate samples. The chemical species responsible for these Ames test indications were soon found not to be the compounds of historical attention, such as BaP, and the search for these chemical mutagens has been a major theme in research efforts since the Ames test was applied to diesel emissions. The validity of sampling procedures, the potential for artifactual mutagen formation, the evolution of bioassay methods as research tools, and the partial correlation of bioassay data with nitro-PAH species have all been active topics since the chemical quest for the mutagen identification began. The important questions about what happens to diesel particulate once emitted to the atmosphere (as contrasted to a dilution tunnel) form an entire field in complexity, experimentation and interpretation.

Particulate emission standards and measurement protocol for certification of 1981 and later model year new cars were promulgated by EPA in 1979. While the measurement protocol does not address sampling for either mutagens or PAH's, the mass emissions measurement protocol has come into general use by most researchers.

The new car certification data have been complemented by very little in-use diesel particulate data obtained by re-testing after mileage accumulation.

The present study was thus designed to explore several aspects of the diesel emissions field by examining a diverse sample of consumer operated diesel vehicles over a period of significant mileage accumulation. Information was needed, for instance, on the following questions to further the understanding of diesel emissions: How do particulate mass emissions vary among vehicles, with the age of vehicles, among type of vehicle operations, and for fuel/oil types encountered among in-use vehicles? Beyond mass emission questions, how does particulate character (extractible, residue, bioassay activity) change with vehicle operation and fuel/oil variations? Which chemical species in particulate extract are significant in the extract bioassay results? How can vehicle particulate emissions be measured in real-time rather than as integrated test-cycle averages from filter samples? How can the accumulated data from in-use diesels be analyzed to reveal trends that connect project data elements that would be isolated pieces of information if taken alone?

VEHICLE SAMPLE GROUP

The vehicle sample for this study included 21 in-use diesels. Most of these vehicles were tested repeatedly over a 28-month period of mileage accumulation. Since all vehicles in the sample group did not accumulate mileage at the same rate, the total number of vehicle tests were not the same for all sample group vehicles. The mileage accumulation intervals between vehicle tests averaged 12,000 miles, but no strict mileage interval was used, in response to the varieties of driving encountered by the vehicles. Since a goal of the study was to retest the same vehicles, the vehicles in the study did not include new diesel engine types that were introduced to the market during the course of the study.

Table 3.1 lists each sample group vehicle by a project "Car #" identifier which is used in subsequent data presentations. Table 3.1 also lists the make, model, model-year, engine displacement/cylinder configuration, transmission type, and emission chassis dynamometer road-load and inertia settings used for testing.

Referring to sample group vehicles by the Car # identifiers, some further information on the background of the vehicles may provide useful information for understanding project results: Cars #1 and #5 were procured by New York State to provide loan vehicles to private vehicle owners who permitted their vehicles to be tested in the project. These two vehicles were also used extensively for project testing needs for collection of large particulate samples, protocol development, etc. These vehicles received normal maintenance by project staff.

Cars #2 and #3 were operated by the New York State Thruway Authority as part of their normal administrative fleet. Car #10, a Thruway Authority Dodge pickup truck equipped with a Mitsubishi diesel engine, was included in the study to obtain comparison data from an engine type not in widespread use.

Car #11, a privately owned Volkswagen Rabbit, entered the project with 120,000 miles, and was last tested at 170,000 miles, and thus was the only project vehicle with testing at such high mileage.

Car #18 was the only 1980 model-year 5.7 L Oldsmobile diesel in the sample group. This vehicle did not have emissions which were typical of the 1979 Oldsmobiles. Since it was the only 1980 Oldsmobile in the group, and numerous design changes were made between the 1978-79 and 1980 5.7 L engines, subsequent groupings of General Motors 5.7 L engines in this paper exclude this vehicle. Thus the emissions data presented for the GM 5.7 L diesels pertain only to 1979 model year designs.

Car #20 was a 1978 General Motors 5.7 L diesel tested only once to evaluate the effect of an experimental crankcase oil additive, and thus the results from this test are not included in any composite emission results presented for the General Motors 5.7 L diesel vehicles.

Car #21, a 1973 Dodge van retrofitted in 1975 with a Chrysler-Nissan CN6-33 diesel engine, was tested to obtain comparison data. This type of engine was used in the New York City diesel taxicab study (28).

Where applicable throughout this report, the vehicles have been divided into groups according to manufacturer. The groups are:

GM: Cars# 2, 3, 4, 5, 7 and 16;
VW: Cars# 1, 6, 8, 9, and 11;
MB: Cars# 12, 13, 14, and 19;
OTHER: Cars# 10, 15, 17, 18, and 21.

The privately owned in-use vehicles were solicited by letter to diesel vehicle registration holders in the Albany, New York area. In consideration for the use of their vehicle for testing purposes, the owner received a loan vehicle during the test, an oil/filter change as part of the test, a full fuel tank upon the return of their vehicle, and two car wash tickets.

TABLE 3.1 - VEHICLE SPECIFICATIONS AND DYNAMOMETER TEST CONDITIONS

CAR #	YEAR	MAKE	MODEL	ENGINE DISPLACMENT		TRANS-MISSION	DYNAMOMETER	
							H.P.	I.W.
1	79	VW	Rabbit	I-4	1.5 L	M4	7.3	2250
2	79	OLDS	Cutlass Cruiser	V-8	5.7 L	A3	12.5	4000
3	79	OLDS	Cutlass Cruiser	V-8	5.7 L	A3	12.5	4000
4	79	OLDS	98 Regency	V-8	5.7 L	A3	12.8	4500
5	79	OLDS	Cutlass Cruiser	V-8	5.7 L	A3	12.5	4000
6	80	VW	Rabbit	I-4	1.5 L	M5	6.8	2250
7	79	CADILLAC	Eldorado	V-8	5.7 L	A3	10.6	4500
8	78	VW	Rabbit	I-4	1.5 L	M4	7.3	2250
9	79	VW	Rabbit	I-4	1.5 L	M4	7.3	2250
10	78	DODGE	D-10 Mitsubishi	I-6	4.0 L	A3	14.4	5500(+)
11	77	VW	Rabbit	I-4	1.5 L	M4	7.3	2250
12	77	M-B	240-D	I-4	2.4 L	M4	12.3	3500
13	78	M-B	300-CD	I-5	3.0 L	A4	13.2	4000
14	79	M-B	240-D	I-4	2.4 L	M4	12.6	3500
15	79	AUDI	5000	I-5	2.0 L	M5	11.8	3000
16	79	OLDS	Delta 88	V-8	5.7 L	A3	13.3	4500
17	79	PEUGEOT	504	I-4	2.3 L	M4	10.7	3500
18	80	OLDS	Cutlass Cruiser	V-8	5.7 L	A3	12.6	4000
19	79	M-B	300-SD (Turbo)	I-5	3.0 L	A4	13.0	4000
20	78	OLDS	Delta 88	V-8	5.7 L	A3	13.3	4500
21	78	DODGE	Tradesman 200	I-6	3.3 L	A3	12.0	4000

MILEAGE FREQUENCY OF TESTS

The total mileage accumulation by the sample group during the project was in excess of 700,000 miles - an average of about 35,000 miles per vehicle. Figure 3.1 is a mileage test point roster showing the odometer readings on each vehicle for its tests. Figure 3.1 also shows how all 80 tests are distributed as a function of accumulated mileage. The 10-50,000 mile band contains 48 (60%) of all project tests and the 50-100,000 mile band contains 23 (30%) of the tests.

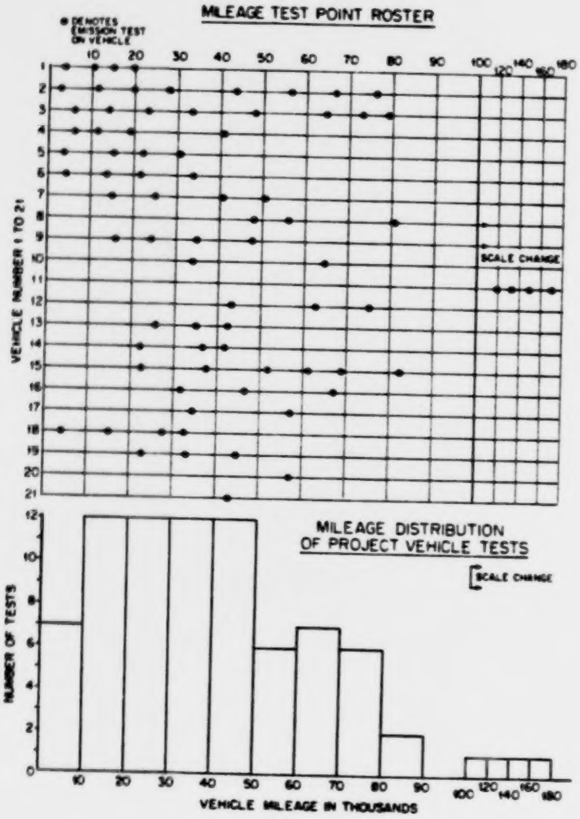


Figure 3.1 Mileage test point roster and mileage distribution of vehicle tests.

Sample Group and Vehicle Test Distributions

Table 3.2 provides a breakdown of the sample group by manufacturer, model year, and number of tests by manufacturer. Fifty-seven percent of the fleet were 1979 model year and 68% of the tests were performed on these vehicles. The General Motors group comprised 38% of the fleet and 45% of the tests. Cars #2 and #3 alone accounted for 20% of all tests. Figures 3.2 and 3.3 show the chronological distribution of tests over the calendar time frame of the in-use testing and the seasonal distribution of tests by month, respectively. The time of year when a test was performed could affect results of tests performed with "as received" fuel. By chance

TABLE 3.2 - VEHICLE SAMPLE GROUP BY MODEL YEAR

MANUFACTURER	MODEL YEAR <1977	1977	1978	1979	1980	TOTAL VEHICLES	TOTAL TESTS
GENERAL MOTORS	0	0	1	6	1	8	36
VOLKSWAGEN	0	1	1	2	1	5	20
MERCEDES-BENZ	0	1	1	2	0	4	12
AUDI	0	0	0	1	0	1	6
PEUGEOT	0	0	0	1	0	1	3
MITSUBISHI	0	1	0	0	0	1	2
NISSAN	1	0	0	0	0	1	1
TOTALS	1	2	4	12	2	21	80

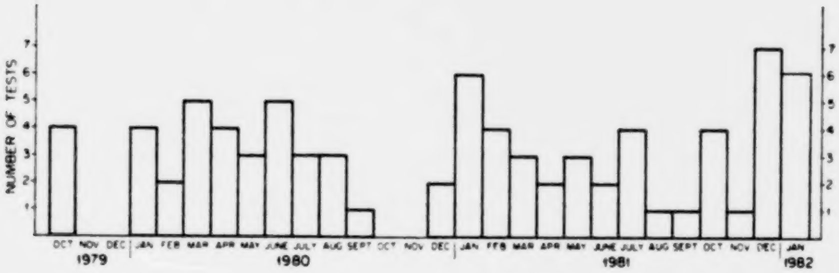


Figure 3.2 Chronological distribution of vehicle tests.

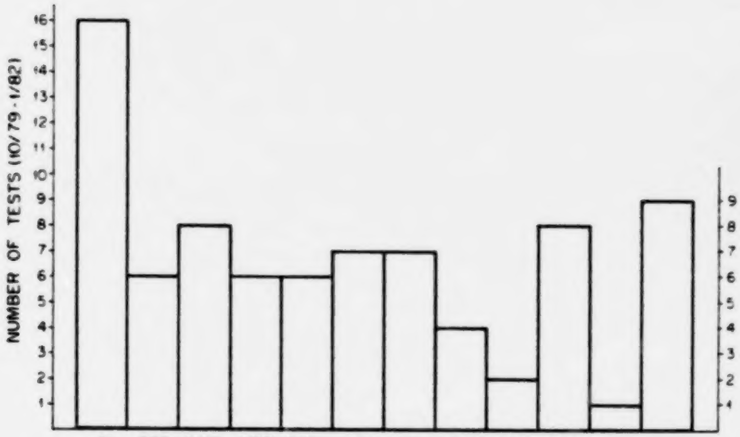


Figure 3.3 Monthly distribution of vehicle tests.

almost half of the tests were performed from December to March, when diesel fuel commonly contains additives. Tests performed in this time period would have the largest differences between "as-received" and control fuel.

Vehicle Test Protocol

The chemical and bioassay characterizations of diesel particulate are, at present, fields of continuing research and development. At the initiation of this project, the state of the art in these fields impacted upon the vehicle testing protocol. Since little information was available on, for instance, how vehicle test conditions affected bioassay results, a lengthy test protocol was adopted to comprehensively measure the vehicle emissions beyond what would have been required if the only goal of the study was to measure vehicle emissions.

The desire to test the vehicles in "as-received" condition, and the need for some standardized test condition was met by doing both. Thus each complete "vehicle test" was composed of repeated "test phases". Each test phase included five or six types of vehicle operation to examine their differences among modes of operation. Since little data were available on pre-conditioning effects, special tests were performed to determine the impact of engine operation modes immediately prior to a vehicle test.

Vehicle Test Cycles

The vehicle test cycles used in this study were: the new vehicle emissions certification driving schedule (Federal Test Procedure - FTP), the Congested Freeway Driving Schedule - (CFDS), the Highway Fuel Economy Test -(HFET), a steady-speed 50 mph cruise (50C), idle operation at zero vehicle speed with vehicle in neutral or "park" (IDLE), and the New York City Cycle (NYCC). Although NYCC has frequently appeared in the technical literature, its origins have not been well-documented. The NYCC was developed by Alfred DeFilippis and Joe Mariano of the New York City Department of Environmental Protection to represent driving conditions in highly congested urban traffic (39). Speed-time data from midtown Manhattan were used in a stochastic model that examined moments up to the third order to generate speed-time tables for testing purposes. Vehicle acceleration and deceleration halves of the velocity-acceleration plane were treated separately to reflect vehicle differences implied by these mathematically inverse, but operationally distinct, modes. Specific details about the length, average speed, number of vehicle stops/mile, etc. for the other driving cycles are available in various reference sources and will not be tabulated here (30).

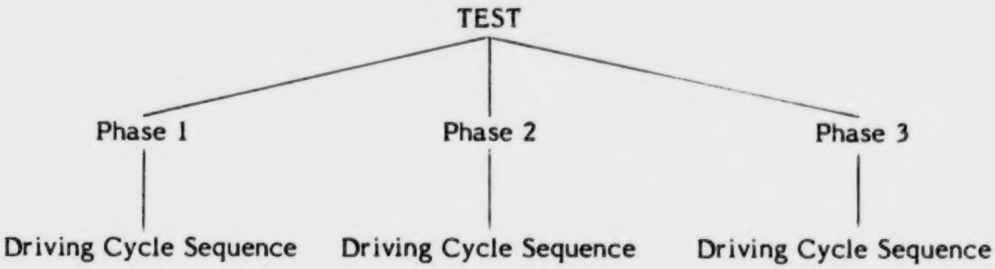
The vehicle test protocol was designed to provide insight into several areas of diesel emissions for which little or no information was available. Among these were:

- the variation of particulate and gaseous emissions with vehicle age, fuel, lubricating oil types, and driving cycle;
- the variation of particulate character (extract, residue and bioassay) with the above parameters;
- the variation of emissions from day-to-day and the reproducibility of the results of a driving cycle;
- the variations among vehicles of the same type and between different groups of vehicles.

To anticipate these topics from in-use vehicles over a two-year testing period, a test protocol employing three replicate driving cycle sequences was adopted, each with different fuel/lubricating oil test conditions. Within project documentation, each of these conditions was labeled as a "Phase". Each of the three phases thus included separate vehicle gaseous/particulate measurements for a sequence of driving cycles. The three phases corresponded to the following vehicle fuel/lubricating oil conditions:

Phase 1 = vehicle tested "as-received".
Phase 2 = project control fuel, "as-received" oil.
Phase 3 = project control fuel, fresh oil of manufacturer specification.

When an in-use vehicle was procured for testing, the entire data accumulation from that procurement was labeled a "Test".



The original driving cycle sequence is given in Table 3.3a as a list of the driving cycles and vehicle soak conditions employed. After 34 complete vehicle tests, the project data were analyzed and reported (31), and at this point the test protocol was modified. The changes were: 1) All Phase 2 testing was eliminated, leaving only Phase 1 and Phase 3 as a complete vehicle test for tests beyond #34, and 2) The driving cycle sequence was modified as shown in Table 3.3b.

TABLE 3.3. VEHICLE TEST DRIVING CYCLE SEQUENCES

A	B
Vehicle Tests 1-34	Vehicle Tests 35-80
50C, 30 min*	50C, 15 min*
50C, 30 min.	
CFDS	
HFET X 3	HFET X 3
SOAK, overnight	SOAK, overnight
FTP	FTP
CFDS	CFDS
HFET X 3	HFET
IDLE, 30 min	NYCC
	50C, 15 min
	IDLE, 15 min
Repeated for each of 3 fuel/ oil combinations= Phase 1, 2, 3	Repeated for each of 2 fuel/ oil combinations= Phase 1, 3

*Pre-Test conditioning, no data taken.

Both driving cycle sequences given in Table 3.3 began with an afternoon portion, followed by an overnight soak at laboratory conditions, and concluding with a morning portion that started with an FTP. Sufficient duplicate testing of the same driving cycle was intentionally included to document particulate and particulate character changes due to changes during a test phase. After test 34, some of this emphasis was dropped, and the New York City Cycle added to examine slow speed vehicle operation. The test sequence spanned vehicle modes from idle to 50 mph, and driving cycles with a wide range of speed variability.

Each complete vehicle test, with its multiple phases and cycle sequence in each phase, required almost one week of work. The project included over 3,200 filter measurements of particulate and 1,800 50 cm x 50 cm filter/solvent extractions. Project archives contain individual extract, fuel, oil, and particulate residue samples from the many test conditions. This report, assembled a few months after the completion of vehicle testing, summarizes and analyzes data to the extent possible within that time frame. However, the archival samples represent a potentially fertile area for future studies.

SECTION 4

GASEOUS AND PARTICULATE EMISSIONS

SUMMARY

This section presents Phase 3 emissions and fuel economy data by vehicle group for the FTP (Table 4.1), CFDS (Table 4.2), HFET (Table 4.3), 50C (Table 4.4), NYCC (Table 4.5) and IDLE (Table 4.6). Each table entry consists of the mean value of a parameter for all tests for the given vehicle group, the standard deviation, σ, of that set and the coefficient of variation, CV, % (σ/mean x 100). This form of presentation gives both absolute emissions and an indication of the observed "spread" in the data so that graphical differences shown in subsequent discussions will be more meaningful.

The coefficients of variation in Tables 4.1-4.6 show that the heterogeneity of a vehicle group depends very strongly on the parameter of interest. Gaseous emissions for these cycles have CV's in the range of 25% to 67% for hydrocarbons but only in the range of 11% to 26% for carbon monoxide and nitrogen oxides. Particulate and residue CV's range from 10% to 48% while extract has very high CV's, ranging from 35% to 93%. The factors causing high coefficients of variation for extract are likely the same as those which affect the hydrocarbons. Fuel economy is the most consistent parameter having a CV range of only 4% to 9% except for the IDLE where fuel economy in minutes per gallon has a CV of 8-16%.

Mean values for these parameters and several other parameters on an individual vehicle basis are presented in Appendix A for both Phase 3 and Phase 1.

DRIVING CYCLE EFFECTS

Introduction

This section presents the data with respect to effects of the various driving cycles. All data in this section are averages of all available data for a given cycle. For the first 34 vehicle tests particulate data were collected from the FTP, CFDS, HFET, 50C and IDLE cycles but gaseous data were collected only from the FTP, CFDS, and HFET. For the last 46 tests both particulate and gaseous data were collected from these five cycles as well as from the NYCC. Although the figures which follow present averages for specific parameters and cycles, some averages are necessarily based on fewer tests due to the absence of gaseous or particulate data.

Particulate, Residue and Extract

The definition of diesel "particulate" is operational as opposed to exact. It is operational because it is based on the conditions of measurement rather than the

TABLE 4.1. - SUMMARY OF FTP PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

		GM			VW			MB	
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	0.89	0.19	22	0.36	0.07	19	0.51	0.07	14
RESIDUE, g/mi	0.65	0.13	20	0.31	0.07	23	0.48	0.08	16
EXTRACT, g/mi	0.25	0.16	63	0.08	0.03	38	0.08	0.04	47
% EXTRACTIBLE	26.3	11.0	42	21.0	7.6	36	13.8	6.9	50
HYDROCARBONS, g/mi	0.65	0.21	32	0.29	0.07	25	0.28	0.12	42
CARBON MONOXIDE, g/mi	1.69	0.22	13	1.11	0.18	16	1.25	0.21	17
NITROGEN OXIDES, g/mi	1.71	0.19	11	0.97	0.16	17	1.58	0.24	15
FUEL ECONOMY, mpg	20.0	1.0	5	43.1	1.7	4	24.7	2.20	9

TABLE 4.2. SUMMARY OF CFDS PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

		GM			VW			MB	
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	0.62	0.20	33	0.34	0.08	24	0.43	0.06	14
RESIDUE, g/mi	0.39	0.11	27	0.26	0.07	27	0.37	0.07	19
EXTRACT, g/mi	0.22	0.16	73	0.08	0.03	40	0.06	0.03	49
% EXTRACTIBLE	33	14	41	23	8	35	15	8	51
HYDROCARBONS, g/mi	0.41	0.16	38	0.26	0.08	30	0.17	0.08	45
CARBON MONOXIDE, g/mi	1.12	0.14	13	0.92	0.21	23	0.90	0.13	14
NITROGEN OXIDES, g/mi	1.38	0.15	11	0.83	0.20	24	1.35	0.19	14
FUEL ECONOMY, mpg	27.4	1.1	4	53.6	2.6	5	31.1	2.7	9

TABLE 4.3. SUMMARY OF HFET PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

		GM			VW			MB	
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	0.49	0.20	42	0.30	0.07	25	0.39	0.06	14
RESIDUE, g/mi	0.29	0.11	40	0.24	0.07	29	0.34	0.06	19
EXTRACT, g/mi	0.20	0.16	78	0.07	0.03	41	0.06	0.03	58
% EXTRACTIBLE	37.7	15.7	42	23.2	8.6	37	14.6	8.6	58
HYDROCARBONS, g/mi	0.33	0.14	42	0.20	0.06	30	0.13	0.06	49
CARBON MONOXIDE, g/mi	0.95	0.10	11	0.77	0.19	24	0.85	0.12	14
NITROGEN OXIDES, g/mi	1.36	0.16	11	0.85	0.22	26	1.34	0.20	15
FUEL ECONOMY, mpg	30.1	1.27	4	57.2	3.22	6	32.7	3.0	9

TABLE 4.4. SUMMARY OF 50C PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

		GM			VW			MB	
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	0.41	0.20	48	0.29	0.08	29	0.37	0.07	20
RESIDUE, g/mi	0.21	0.09	40	0.23	0.07	32	0.31	0.07	21
EXTRACT, g/mi	0.20	0.16	82	0.06	0.03	48	0.06	0.03	57
% EXTRACTIBLE	43	17	40	21.4	8	38	15	8	50
HYDROCARBONS, g/mi	0.41	0.18	43	0.21	0.08	39	0.14	0.06	45
CARBON MONOXIDE, g/mi	0.94	0.11	12	0.83	0.30	36	0.82	0.15	18
NITROGEN OXIDES, g/mi	1.30	0.15	12	0.90	0.26	29	1.2	0.11	9
FUEL ECONOMY, mpg	32.2	1.5	5	59.5	3.4	6	34.4	2.4	7

TABLE 4.5. SUMMARY OF NYCC PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

	GM			VW			MB		
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	1.88	0.23	12	0.44	0.05	10	0.87	0.12	14
RESIDUE, g/mi	1.33	0.14	10	0.30	0.06	19	0.75	0.12	16
EXTRACT, g/mi	0.55	0.19	35	0.14	0.06	45	0.13	0.05	38
% EXTRACTIBLE	27.9	8.0	29	31.8	12.5	39	15.1	5.13	34
HYDROCARBONS, g/mi	1.69	0.51	30	0.49	0.33	67	0.47	0.25	52
CARBON MONOXIDE, g/mi	4.02	0.53	13	2.06	0.53	26	2.27	0.50	22
NITROGEN OXIDES, g/mi	2.82	0.37	13	1.53	0.20	13	2.32	0.27	12
FUEL ECONOMY, mpg	11.1	0.8	7	29.4	1.4	5	17.0	1.3	8

TABLE 4.6. SUMMARY OF IDLE PARTICULATE AND GASEOUS EMISSIONS - PHASE 3

	GM			VW			MB		
Emission	Mean	σ	CV,%	Mean	σ	CV,%	Mean	σ	CV,%
PARTICULATE, g/mi	0.188	0.028	15	0.017	0.011	63	0.053	0.014	26
RESIDUE, g/mi	0.145	0.018	13	0.007	0.003	45	0.045	0.013	28
EXTRACT, g/mi	0.042	0.021	48	0.011	0.009	93	0.008	0.003	36
% EXTRACTIBLE	22	8	35	53	21	40	15	5	35
HYDROCARBONS, g/mi	0.230	0.111	48	0.058	0.059	103	0.040	0.030	74
CARBON MONOXIDE, g/mi	0.549	0.103	19	0.186	0.124	67	0.153	0.027	18
NITROGEN OXIDES, g/mi	0.160	0.033	21	0.099	0.026	26	0.128	0.032	25
FUEL ECONOMY, min/gal	163	13	8	561	50	9	346	57	16

properties of the substance. The mass of particulate is determined from the weight gain of a specified filter at specified temperature and flow rate ranges. Anything collected by the filter (except uncombined water - for which no correction is made) is called particulate.

The particulate itself can be further fractionated by means of solvent extraction. Again, an operational definition applies. The "extract" is that material which is removed by a particular solvent under the specified conditions. In addition, the material which is not extracted can be called the "residue". Because of the complimentary nature of extract and residue and the existence of possible carcinogens in the extract, it has been customary to use only the extract and to express it as a percentage of the particulate, i.e., percent extractible rather than as a mass emission in itself.

With proper choice of solvent and extraction conditions almost all organic (as well as some inorganic) compounds can be removed from the particulate. The remaining "residue" is primarily carbon with insoluble inorganics and organics. Production of the carbon (frequently called "soot") in the diesel engine has been extensively studied. Although the extract has received much attention in the form of chemical analysis and biological hazard assessment, only limited work has been conducted to determine the source of the extract and the mechanism by which it becomes "particulate".

There are four locations at which particulate matter could be formed:

(1) the engine cylinders,
(2) the exhaust system,
(3) the dilution tunnel, and
(4) the filter.

The carbon portion of the residue is formed in the engine cylinders as a combustion product. After production, it undergoes physical changes before collection but is probably changed very little in mass. Some of the material produced during combustion is probably solvent extractible hydrocarbon derived material. In the post-combustion section of the sampling system, additional extractible material can be formed by:

(1) absorption/adsorption,
(2) mass diffusion,
(3) condensation, and
(4) chemical reaction.

Often it is the cooling of the exhaust (caused by dilution and heat loss) which promotes the conversion of gaseous material to particulate material via a mechanism involving the above processes. The mass, particle size, shape and surface morphology of the carbon portion could affect the quantity of gaseous material converted into particulate.

In the course of this study we observed that the residue mass was a function of the engine family, driving cycle and operating temperature and did not appear to be influenced by fuel composition, lubricating oil or engine condition (mileage accumulation). We will, therefore, consider residue to be a measurable, reproducible and independent parameter with a physical significance equal to that of the extract.

The effects of driving cycles on the particulate, extract and residue are shown in Figures 4.1, 4.2, and 4.3 for the General Motors, Volkswagen, and Mercedes-Benz groups, respectively. The cycles have been arranged on the x-axis such that the average speed of the cycle (except the IDLE) increases from left to right and the speed variability of the cycle increases from right to left. The General Motors group data show that the main contributor to the cycle-to-cycle difference observed in the particulate was the residue. The extract contribution was relatively constant except for a large increase for the NYCC. The IDLE data (expressed in units of grams/minute) shows a large decrease from the 50C data (expressed in grams/minute) in all three categories. (For comparisons with IDLE data, the 50C data can be easily converted from gram/mile to grams/minute by multiplying by 50/60 or 0.83.)

The Volkswagen group data, Figure 4.2, are very similar to the General Motors group data except that the residue is much less influenced by driving cycle and, therefore, the particulate shows less cycle dependence than did the General Motors group. The IDLE data are very different than for the General Motors group in that both residue and extract are very low both in absolute emission rate and relative to the 50C. This is the only cycle for which the extract is greater than the residue. The very low emissions for this cycle made measurement difficult and the accuracy and precision of IDLE data for Volkswagen is much lower than for any other cycles/makes.

The Mercedes-Benz group data, Figure 4.3, show trends very similar to both the General Motors and Volkswagen groups. The large increase in residue for the NYCC is very similar to that observed for the General Motors group. The large decrease in residue and extract shown for the IDLE is much like that exhibited by the Volkswagen group; but here the residue is clearly the main component of particulate. The extract is very similar to that of Volkswagen in absolute terms for all six cycles.

Figures 4.4, 4.5, and 4.6 compare the vehicle groups for emissions of particulate, residue and extract respectively. Figures 4.4b, 4.5b and 4.6b show the same data as the corresponding "a" figures but normalized to the FTP to better illustrate the cycle

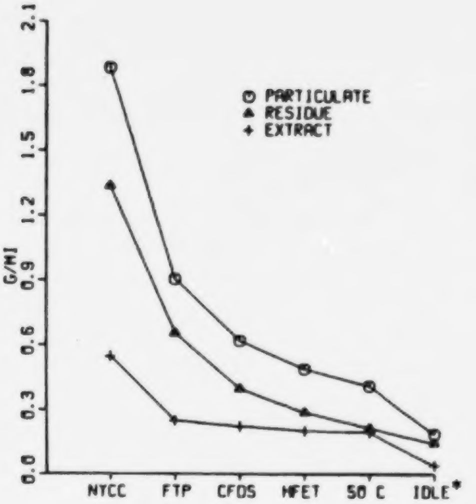


Figure 4.1 Cycle variations of particulate, residue and extract for the General Motors vehicle group.
*IDLE units are g/minute

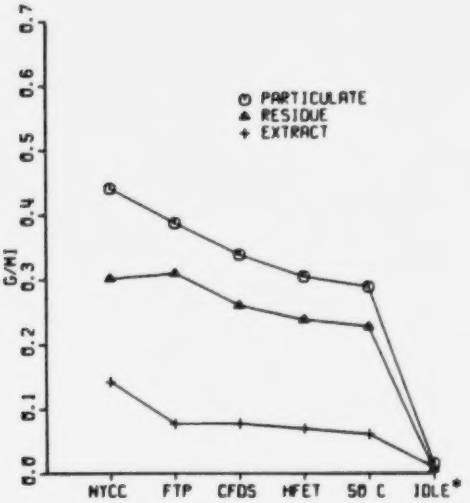


Figure 4.2 Cycle variations of particulate, residue and extract for the Volkswagen vehicle group.
*IDLE units are g/minute

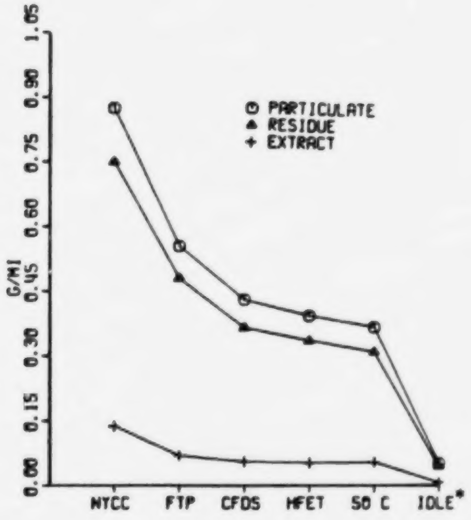


Figure 4.3 Cycle variations of particulate, residue and extract for the Mercedes-Benz vehicle group.
*IDLE units are g/minute

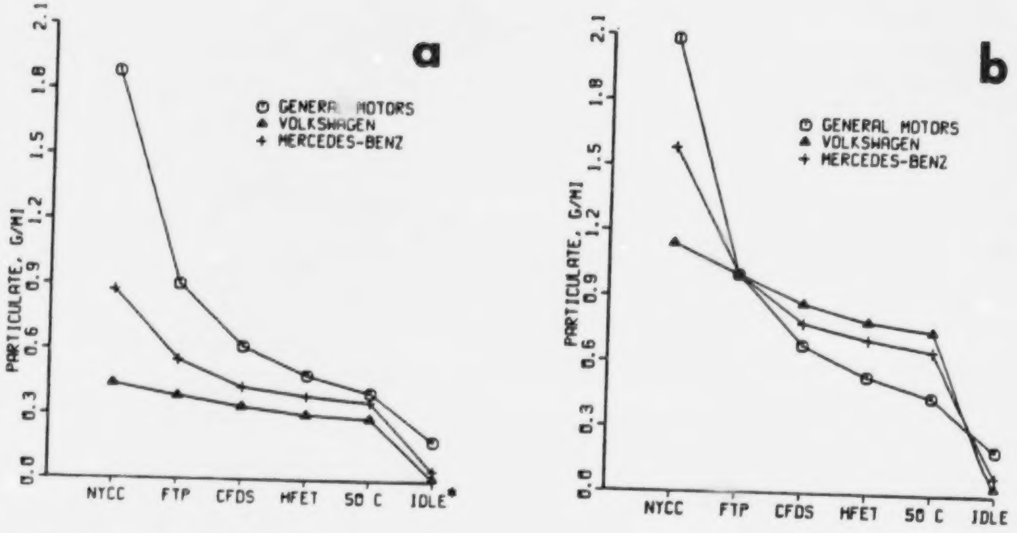


Figure 4.4 Cycle variations of particulate by vehicle group: (a) actual values, (b) normalized to the FTP.
*IDLE units are g/minute

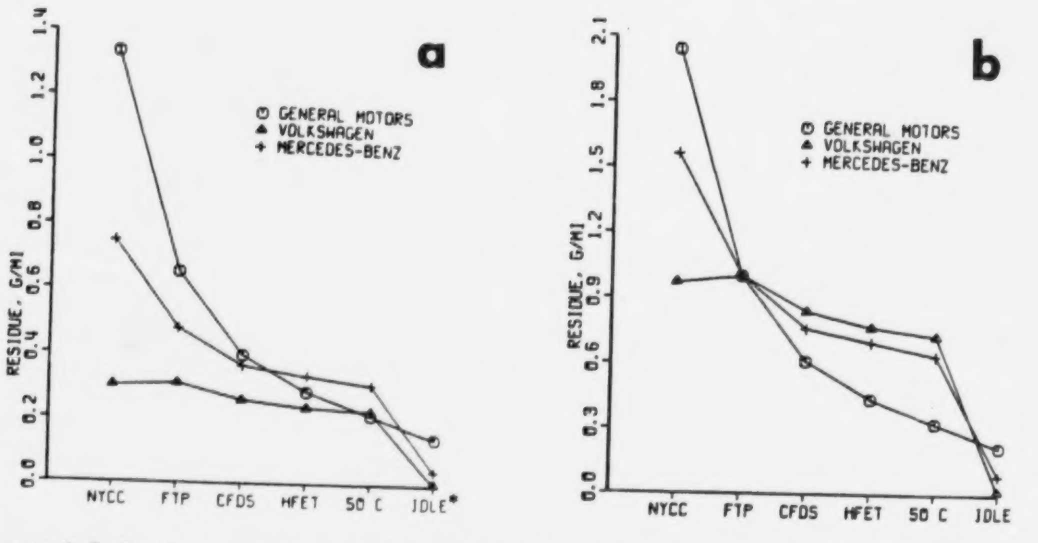


Figure 4.5 Cycle variations of residue by vehicle group: (a) actual values, (b) normalized to the FTP.
*IDLE units are g/minute

sensitivities of the three groups. Figure 4.4 shows trends of increasing particulate with driving cycle: 50 C < HFET < CFDS < FTP < NYCC and by group: VW < MB < GM. The General Motors group shows a strong cycle sensitivity which is much greater than that of the Volkswagen and Mercedes-Benz groups. For the General Motors group, the NYCC particulate is more than double the FTP and the 50C particulate is about one-half the FTP. For the Volkswagen group, in contrast has values of 1.1 and 0.8 times the FTP. The Volkswagen group shows very little cycle sensitivity with only about a 50% increase in particulate from the 50C to the NYCC.

Figure 4.5 shows the cycle-to-cycle trends for residue. The General Motors curve is very different from those for the Volkswagen and Mercedes-Benz groups. The residue for the HFET is lower than that for the Mercedes-Benz group; and the 50C residue is lower than for both the Mercedes-Benz and Volkswagen groups. This trend reversal was not observed for any other emission. Figure 4.5b shows that the General Motors curve is fundamentally different. There is no leveling off of the residue for the CFDS, HFET and 50C to the IDLE. The Volkswagen curve shows almost no difference between cycles except for a large decrease at the IDLE.

Figure 4.6 shows that the extract for the General Motors group is two to three times greater than for the Volkswagen and Mercedes-Benz groups. Cycle variations are relatively small and constant for all groups except for the NYCC which has extract about twice that of the FTP for all groups.

Figures 4.7a and 4.7b show the trends for the percent extractible, (extract/particulate)x100. Comparison of Figures 4.7a and 4.4a shows that the General Motors group percent extractibles are inversely related to the total particulate except for the IDLE which has the lowest value. The Volkswagen group data show a large increase for the NYCC and a very large increase for the IDLE. The IDLE value may be biased to the high side due to difficulties in measuring the small quantities of particulate emitted by the Volkswagens and inclusion of the normally relatively insignificant amount of extract from the filter material itself. The Mercedes-Benz group data showed a very low and very consistent percent extractibles and almost no cycle variation except for a small decrease for the FTP.

Gaseous Emissions

Hydrocarbons--

Average hydrocarbon emissions, g/mi, are shown in Figure 4.8 for all vehicle groups. The most noticeable aspect of this data is the large increase in HC for the NYCC for all vehicle groups. The NYCC HC averages 2.5 times higher than the FTP for the General Motors group and 1.7 times higher than the FTP for the Volkswagen and Mercedes-Benz groups. In all instances the HFET has lower HC than the other driven cycles and the trends of increasing emissions are: HFET < 50C <CFDS <FTP < NYCC and MB < VW <GM.

Carbon Monoxide--

Emissions of CO are shown in Figure 4.9. The General Motors group carbon monoxide emissions are greater than those of the Volkswagen and the Mercedes-Benz groups for all cycles. The Volkswagen and Mercedes-Benz groups are very similar with Mercedes-Benz group slightly higher. All groups have a strong cycle dependence with the NYCC emissions about twice those of the FTP. CO shows a cycle dependence

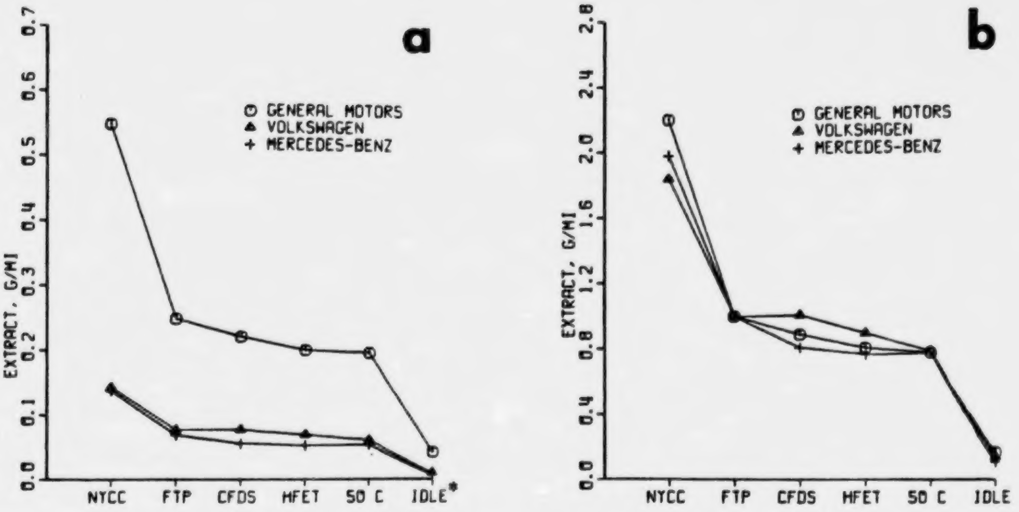


Figure 4.6 Cycle variations of extract by vehicle group: (a) actual values, (b) normalized to the FTP.
*IDLE units are g/minute

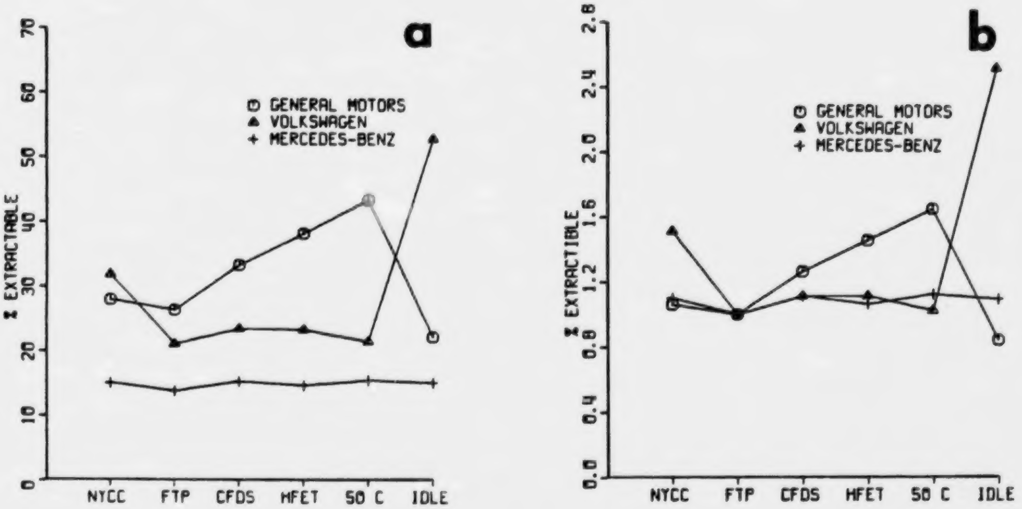


Figure 4.7 Cycle variations of % extractible by vehicle group: (a) actual values, (b) normalized to the FTP.

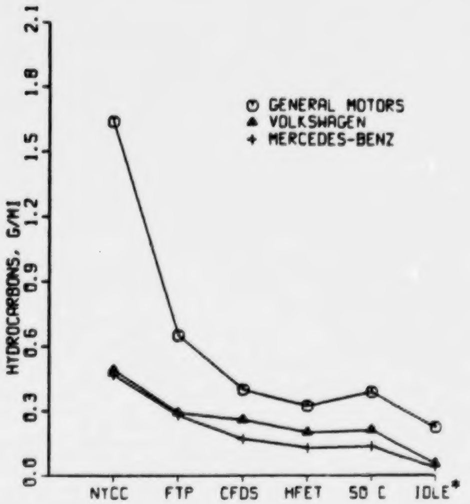


Figure 4.8 Cycle variations of hydrocarbons by vehicle group.
*IDLE units are g/minute

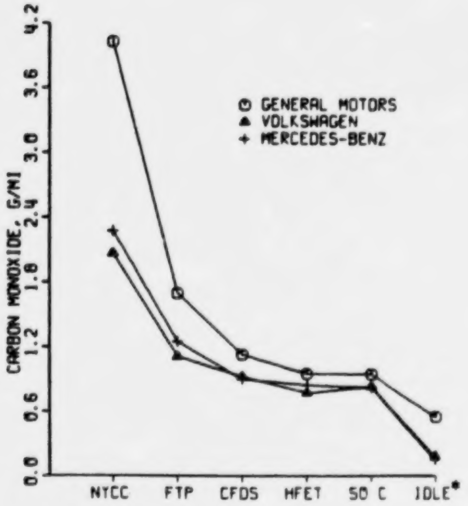


Figure 4.9 Cycle variations of carbon monoxide by vehicle group.
*IDLE units are g/minute

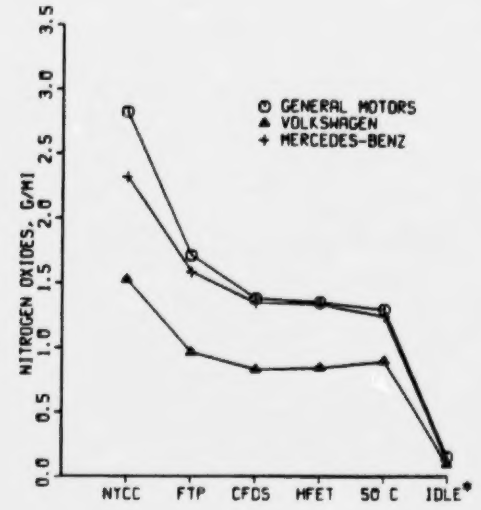


Figure 4.10 Cycle variations of nitrogen oxides by vehicle group.
*IDLE units are g/minute

which is similar to that of HC for the General Motors and Volkswagen groups.

Nitrogen Oxides--

Figure 4.10 shows that NO_x emissions for the General Motors and Mercedes-Benz groups are very similar, with the General Motors group higher for all cycles but deviating significantly only for the FTP and NYCC. The values for the Volkswagen group are roughly 60% of the comparable values for the General Motors or Mercedes-Benz groups. There is a difference among group cycle variations for the CFDS, HFET and 50C. For all groups the IDLE shows a large decrease.

MILEAGE ACCUMULATION EFFECTS

Introduction

This section discusses changes which occurred in emission parameters as the vehicles accumulated mileage. In this study the mileage differences between initial and final tests on an individual vehicle basis ranged from 16,000 to 73,000 miles with an average of 34,600 miles. Annual vehicle mileage accumulation ranged from 8,400 to 36,100 miles with an average of 22,300 miles. It is recognized that the effects of mileage accumulation (and the coincident ageing of the vehicle) can be affected by many parameters which are uncontrolled and largely unknown in this real-world in-use study, such as engine mechanical work, injector timing, adjustments, etc. Table 4.7 gives information on the odometer mileage, test intervals and annual usage of the test vehicles.

The data in this section are from the FTP only. In general the mileage accumulation trends for a given emission parameter did not vary greatly from cycle to cycle.

Particulate Emissions

Emissions collected by filtration on teflon coated glass fiber filters (Pallflex T60A20) under the conditions prescribed by the Federal Test Procedure for light duty diesel vehicles are discussed in this section. The emissions are divided into three categories: (a) particulate, which is the regulated and defined parameter, and its two constituents (b) residue, the remainder after solvent extraction and (c) extract, the soluble organic fraction-SOF.

Particulate --

The effects of mileage accumulation on FTP particulate, g/mi, are shown in Figure 4.11a for the General Motors group, Figure 4.11b for the Volkswagen group and Figure 4.11c for the Mercedes-Benz group. Figure 4.11d shows all three vehicle groups on common axes to allow better visual comparison. The irregular enclosures around the group names are envelopes which contain all values for the respective group. Values for Car #4 and Car #11 are presented separately. All the General Motors vehicles (Figure 4.11a), except Car #16, showed increases in particulate with mileage ranging from slight (Car #3) to very large (Car #4 and Car #2). Increases as great as 50% occurred over the mileage accumulation period. The particulate emissions generally ranged from 0.65 to 0.9 g/mi except for tests on Car #2 after about 30,000 miles and all tests on Car #4.

TABLE 4.7 - MILEAGE STATISTICS FOR TEST VEHICLES AND VEHICLE GROUPS

	Odometer Mileage		Δ	No.	Average Mileage	
Car #	Initial	Final	Miles	Tests	Between Tests	Per Year
2	2,992	76,318	73,326	8	10,475	32,600
3	6,160	79,223	73,063	8	10,438	32,500
4	6,729	40,744	34,015	4	11,338	17,700
5	3,617	30,685	27,068	4	9,023	14,800
7	15,115	50,683	35,568	4	11,858	29,400
16	31,798	67,266	35,468	3	17,734	22,400
GM	11,069	57,487	46,418	31	11,240	23,200
1	3,576	19,753	16,177	4	5,392	8,400
6	4,279	33,825	29,546	4	9,489	16,900
8	48,075	80,920	32,835	4	10,945	17,100
9	16,340	47,764	31,424	4	10,475	18,000
11	119,196	171,199	52,003	4	17,334	32,800
VW	38,293	70,690	32,397	20	10,799	18,700
12	43,444	75,195	31,751	3	15,876	18,100
13	26,006	42,520	16,514	3	8,257	9,000
14	22,317	41,964	19,647	3	9,824	11,200
19	23,043	44,846	21,803	3	10,902	15,400
MB	28,703	51,131	22,429	12	11,215	13,400
10	34,165	64,846	30,681	2	30,681	33,500
15	22,754	82,956	60,202	6	12,040	36,100
17	34,941	77,251	42,310	3	21,155	26,700
18	4,341	32,792	28,451	4	9,484	19,000
ALL			34,593	78	12,580	22,300

The Volkswagen group, Figure 4.11b, exhibited particulate in the range of 0.25 to 0.55 g/mi. All Volkswagens had particulate lower than the lowest General Motors vehicle. No overall mileage accumulation trend was apparent, but individual vehicles showed large relative variations in particulate. Car #1 and Car #9 showed large increases while Car #6 had a large consistent decrease. Car #11, a very high mileage vehicle, had particulate emissions which were average for its group. For Mercedes-Benz vehicles, Figure 4.11c, particulate emissions were in the range of 0.4 to 0.7 g/mi with no apparent mileage trend. Car #12 and Car #13 showed decreases, Car #14 increased, and Car #19 first decreased but then increased.

Residue--

Residue, g/mi, is shown for each vehicle group in Figures 4.12a, 4.12b, and 4.12c and for all groups together in Figure 4.12d. In Figure 4.12a for General Motors, there is a very tight cluster of data in the 0.5 to 0.75 g/mi range with the obvious exception of Car #4 which was much higher. Some vehicles showed slight mileage effects such as the increase noted for Car #5 and the decrease exhibited by Car #16, but in general no overall trend was indicated. The Volkswagen group, Figure 4.12b, had residue which ranged from 0.2 to 0.5 g/mi but was generally below 0.4 g/mi. The Volkswagen data varied more car-to-car than the General Motors group data (with Car #4 excluded). A

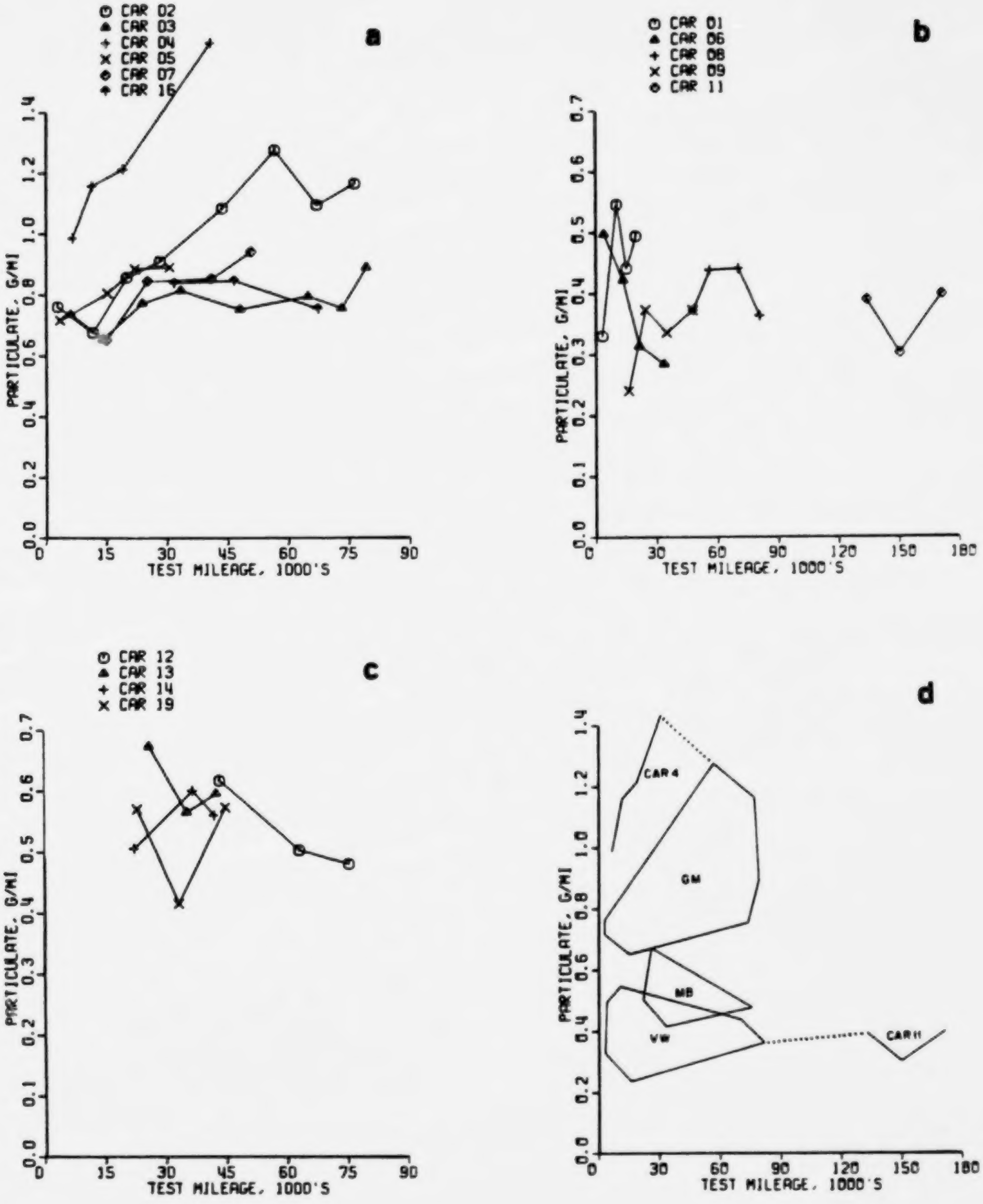


Figure 4.11 Mileage accumulation effects for FTP particulate by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

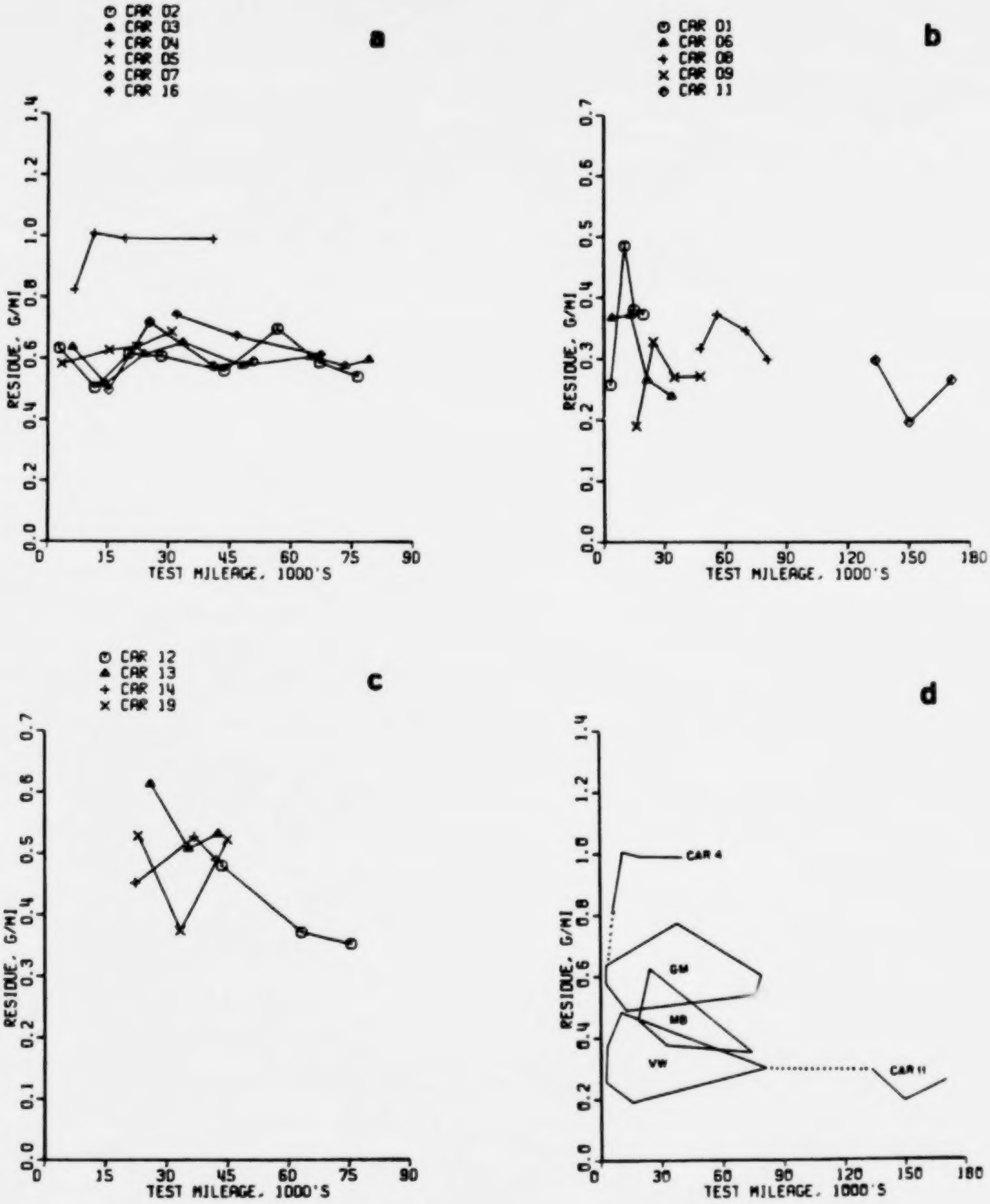


Figure 4.12 Mileage accumulation effects for FTP residue by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

possible cause of this may have been the combination of four model years and two transmission types in the Volkswagen group. The Mercedes-Benz group residue, Figure 4.12c, was in the region of 0.35 to 0.5 g/mi. The trends in residue were identical to those observed for the particulate as the extract was very small and constant.

Extract--

Figures 4.13a, 4.13b, and 4.13c show the variation of extract, g/mi, with accumulated mileage for the General Motors, Volkswagen and Mercedes-Benz groups respectively. Figure 4.13d shows all vehicle groups on common axes. Several General Motors vehicles exhibited very large (3x to 5x) increases in extract during the mileage accumulation period. In three cases (Cars #2, #4 and #7), there were very large increases in the 20,000 to 30,000 mile range. All vehicles exhibited some increase in extract during the mileage accumulation period. Below about 15,000 miles, all values were below 0.2 g/mi but by 40,000 miles the upper range of the General Motors group extract had increased to over 0.6 g/mi. Extract values for the Volkswagen group were very much lower than for the General Motors group, ranging from about 0.05 to 0.15 g/mi. Car #6 showed a large decrease (in a relative sense) after its first test. The other vehicles showed increases after their first tests. Overall, there was no apparent mileage accumulation effect, and the individual extract changes were all less than 0.1 g/mi for the mileage accumulation period. The Mercedes-Benz group, Figure 4.13c, extracts were generally in the 0.04 to 0.07 g/mi range except for Car #12 which had about 0.14 g/mi extract. All Mercedes-Benz vehicles showed high consistency over the mileage accumulation period, and there was no overall mileage effect.

Figure 4.14 combines the emission envelopes of Figure 4.11, 4.12, 4.13 with common axes (Car #11 has been removed for simplicity). From this figure, it is apparent that the increases in particulate for the General Motors group are primarily due to extract. The particulate of the Volkswagen and Mercedes-Benz groups was due primarily to the residue and the extract was small and constant.

Gaseous Emissions

Hydrocarbons--

HC emissions for the FTP are shown in Figure 4.15a for the General Motors group, in Figure 4.15b for the Volkswagen group, in Figure 4.15c for the Mercedes-Benz group and in Figure 4.15d for all groups on common axes. General Motors vehicles generally exhibited significant increases in FTP hydrocarbon emissions, g/mi, with increased mileage. Data on six vehicles for the FTP are shown in Figure 4.15a. These data generally cluster in the 0.45 to 0.7 g/mi range with several notable exceptions. Car #2 showed a doubling of HC between tests at about 30,000 and 45,000 miles. During this period the engine heads were replaced. The changing of the heads or some other alteration (deliberate or accidental) may account for the increased HC. Car #7 showed a similar increase in HC in about the same mileage range.

The Volkswagen group had HC emissions that generally ranged from 0.2 to 0.4 g/mi as shown in Figure 4.15b. Individual vehicle variations with mileage were generally not large or consistent, with both increasing and decreasing trends observed. No overall group trend with mileage was apparent.

The Mercedes-Benz group HC emissions were similar to those of the Volkswagen

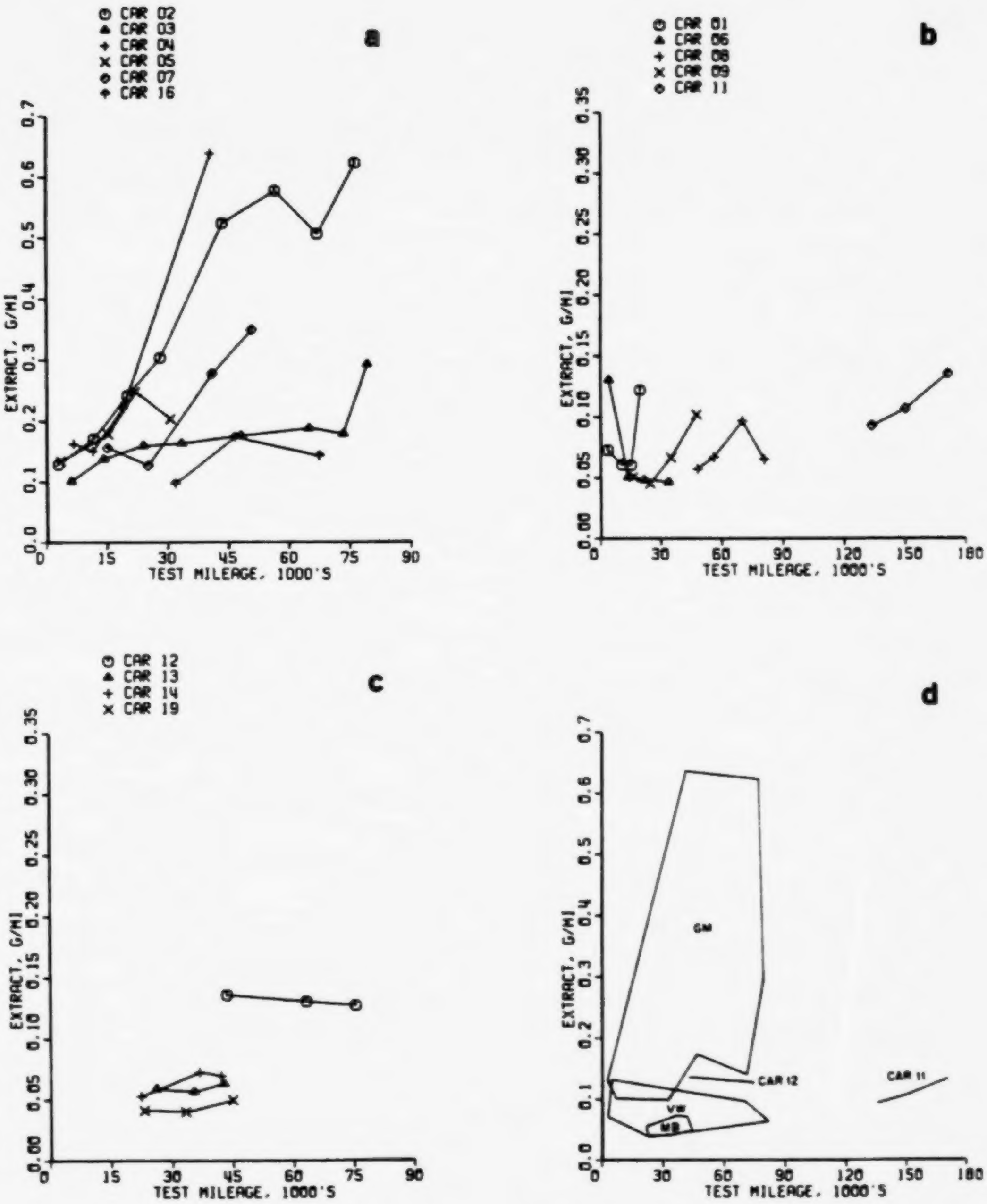


Figure 4.13 Mileage accumulation effects for FTP extract by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

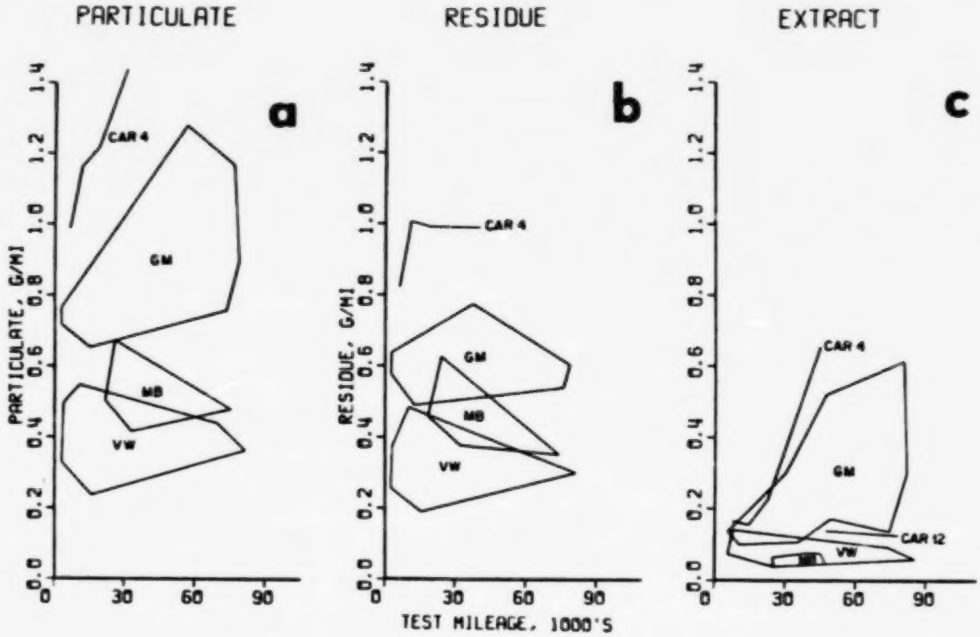


Figure 4.14 Group emission envelopes for: (a) particulate, (b) residue, (c) extract.

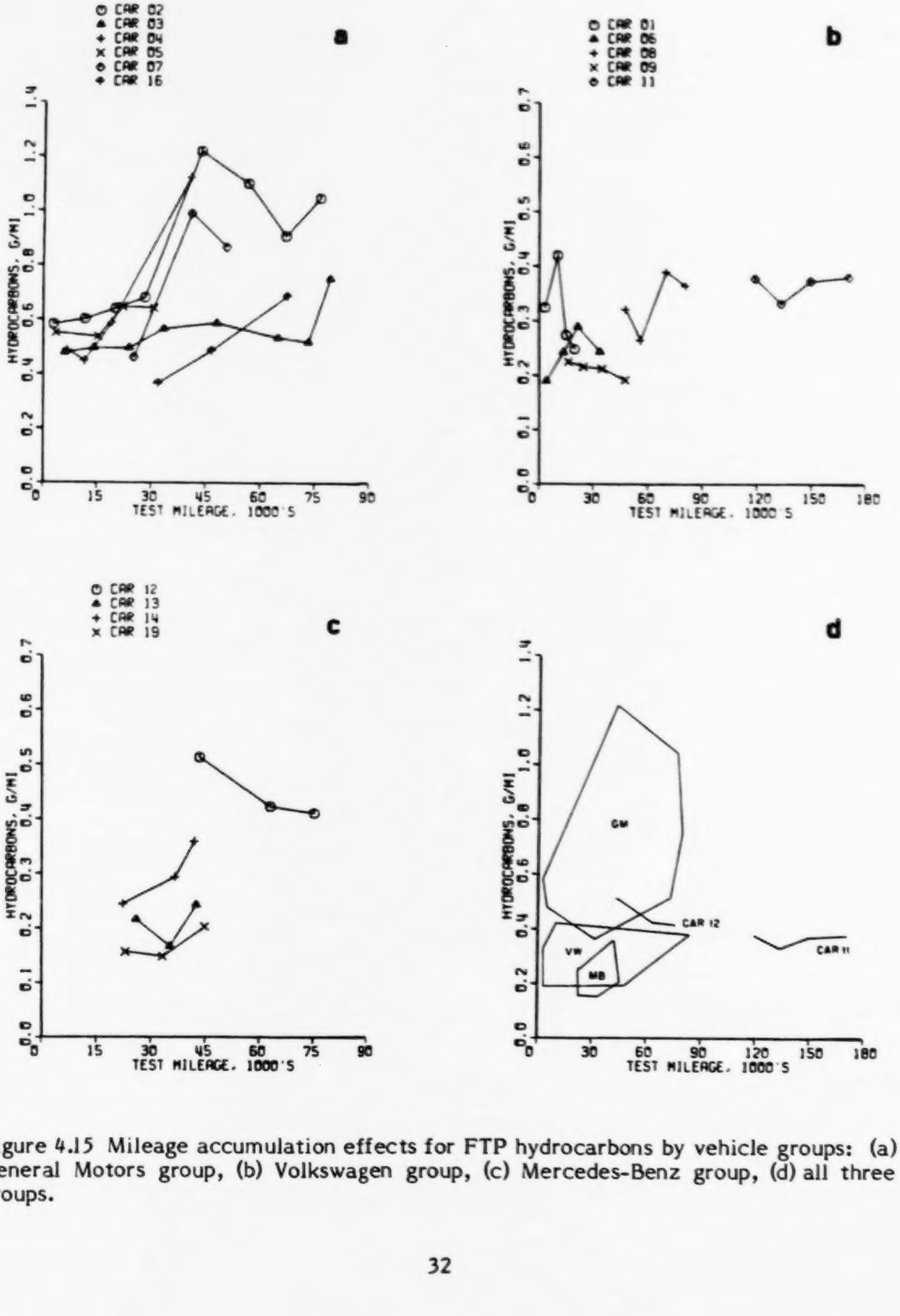


Figure 4.15 Mileage accumulation effects for FTP hydrocarbons by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

group and were in the 0.15 to 0.5 g/mi range as shown in Figure 4.15c. No clear mileage accumulation effects were apparent for the group, and individual vehicles showed different mileage effects.

Carbon Monoxide--

CO emissions for the FTP are shown in Figure 4.16a for the General Motors group, Figure 4.16b for the Volkswagen group, Figure 4.16c for the Mercedes-Benz group, and Figure 4.16d for all groups on common axes. CO emissions for the General Motors group generally ranged from 1.4 to 2.2 g/mi. Mileage accumulation trends varied from almost neutral to about a 30% increase over the course of the tests. Most of the CO mileage trends were very similar to those observed for HC, but the increases were smaller. The Volkswagen group had CO, Figure 4.16b, which ranged from 0.8 to 1.5 g/mi. The CO increased with mileage accumulation for all vehicles; but there was much scatter in the data and no overall mileage trend was apparent. The Mercedes-Benz group, Figure 4.16c, had CO emissions in the 0.9 to 1.6 g/mi range. Unlike the General Motors and Volkswagen groups, the Mercedes-Benz group generally decreased in CO with increasing mileage, but there were insufficient data to establish a definite trend.

Nitrogen Oxides--

The variation of FTP nitrogen oxides with accumulated mileage is shown for the General Motors group in Figure 4.17a, for the Volkswagen group in Figure 4.17b, for the Mercedes-Benz group in Figure 4.17c, and for all groups on common axes in Figure 4.17d. Except for Car #4 (which consistently displayed unusual behavior) all the General Motors vehicles showed decreases in NO_x in the range of 5-20% with accumulated mileage. Car #4 showed a very large and unexplained increase. The General Motors group as a whole showed a decrease in NO_x with accumulated mileage which averaged about 0.2 g/mi per 50,000 miles. The Volkswagen group data were very consistent except for Car #9 and were in the 0.8 to 1.1 g/mi range with no apparent overall trend. All Mercedes-Benz vehicles exhibited decreased NO_x at higher mileage. The rate of decrease was much higher than for the General Motors group, and an overall group decrease with increasing mileage was apparent.

% Extractible--

Extractible data are shown for individual vehicles by vehicle groups in Figures 4.18a, b and c and for the groups as a composite in Figure 4.18d. These figures are very similar to those for extract, g/mi, (Figure 4.13). The General Motors group data are very similar to the extract, g/mi, data except that Car #4 has a % extractible that is more typical of the group. The group as a whole has less scatter than it did for extract. The Volkswagen and Mercedes-Benz groups have % extractible data which are very similar to their extract, g/mi, data.

The General Motors and Volkswagen group show considerable overlap particularly up to about 30,000 miles. The Mercedes-Benz group, however, (with the exception of Car #12) has % extractibles which were lower than all other vehicles. The difference between Car #12 and the other three Mercedes-Benz vehicles may be related to its greater age and higher mileage.

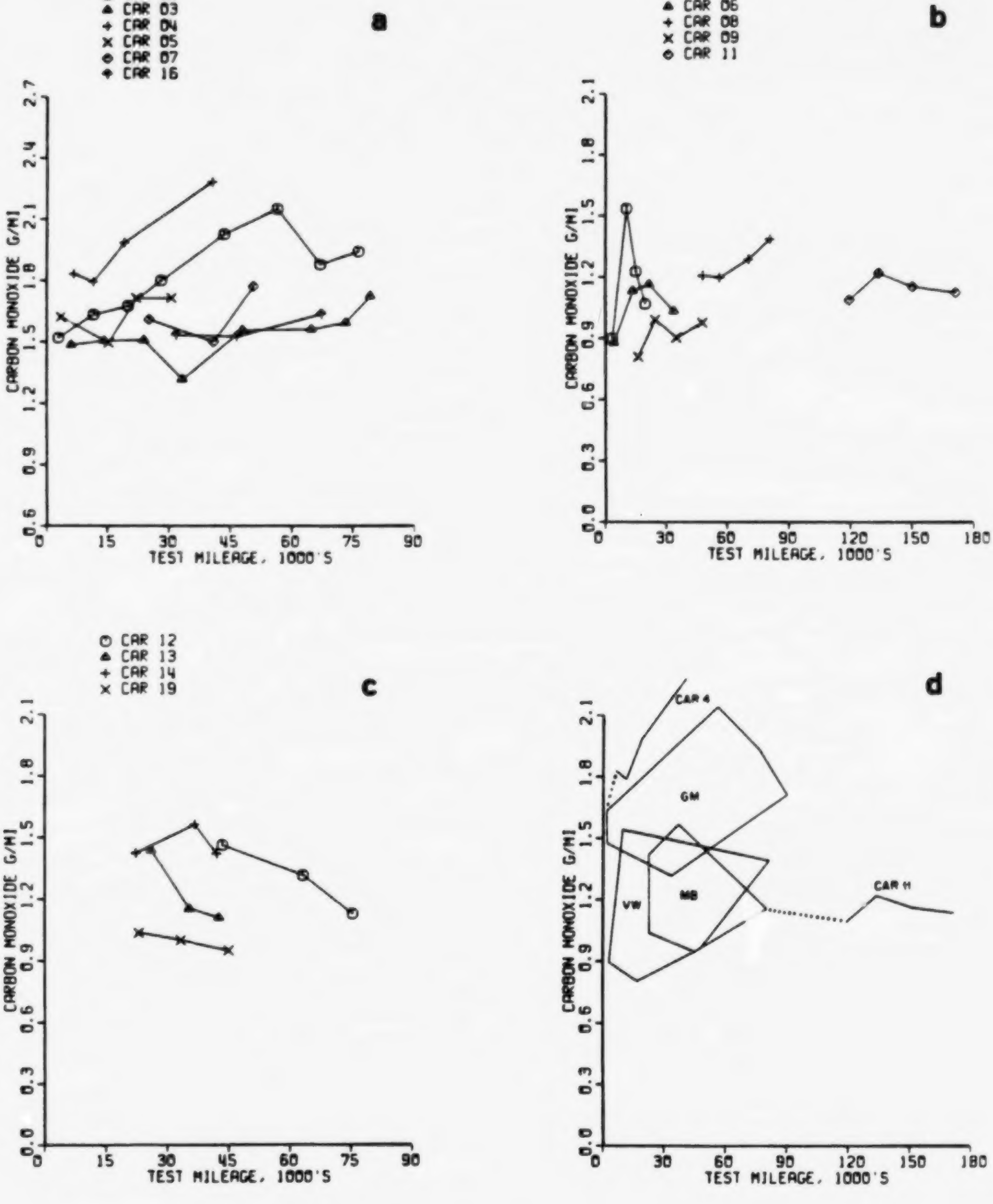


Figure 4.16 Mileage accumulation effects for FTP carbon monoxide by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

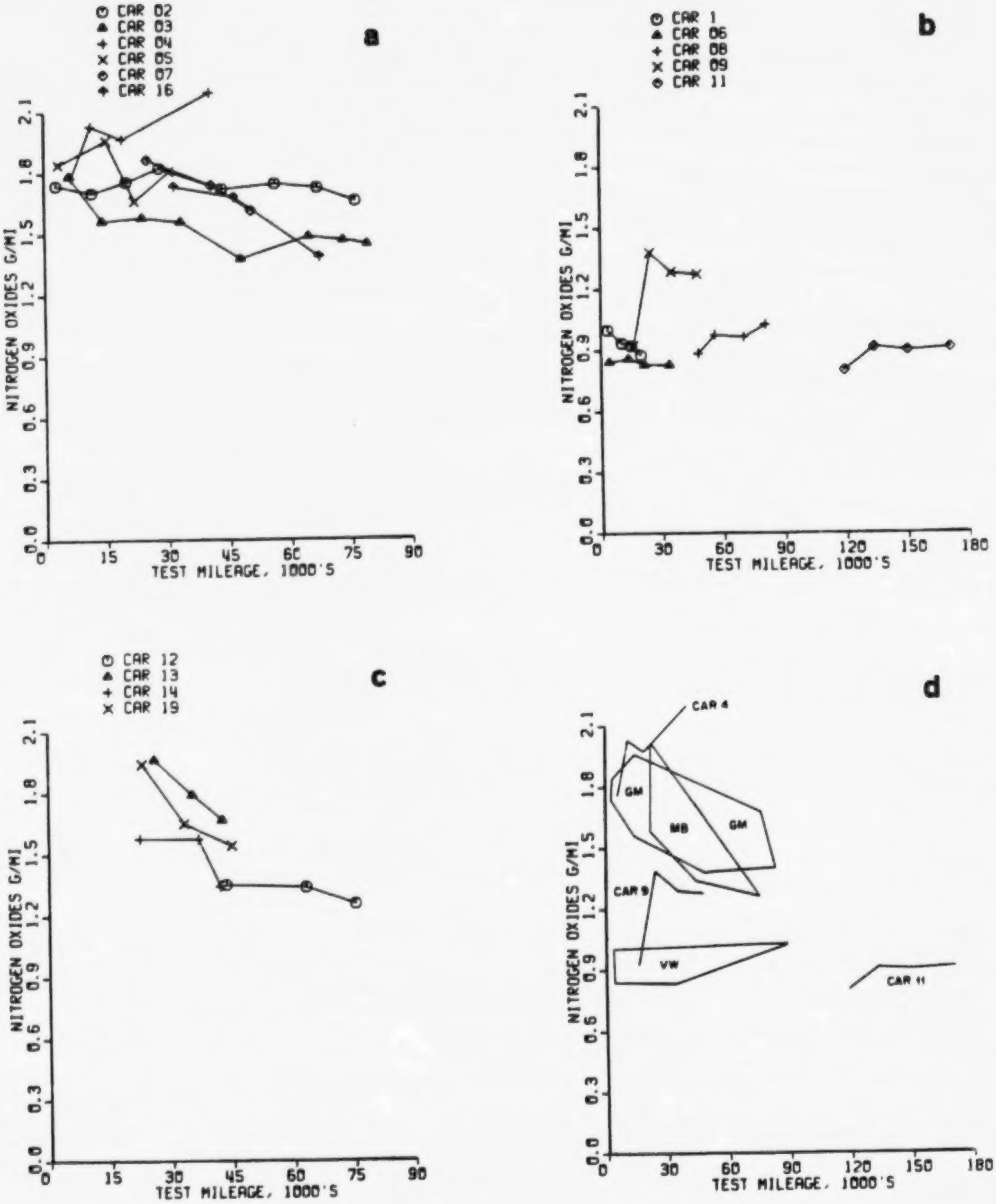


Figure 4.17 Mileage accumulation effects for FTP nitrogen oxides by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

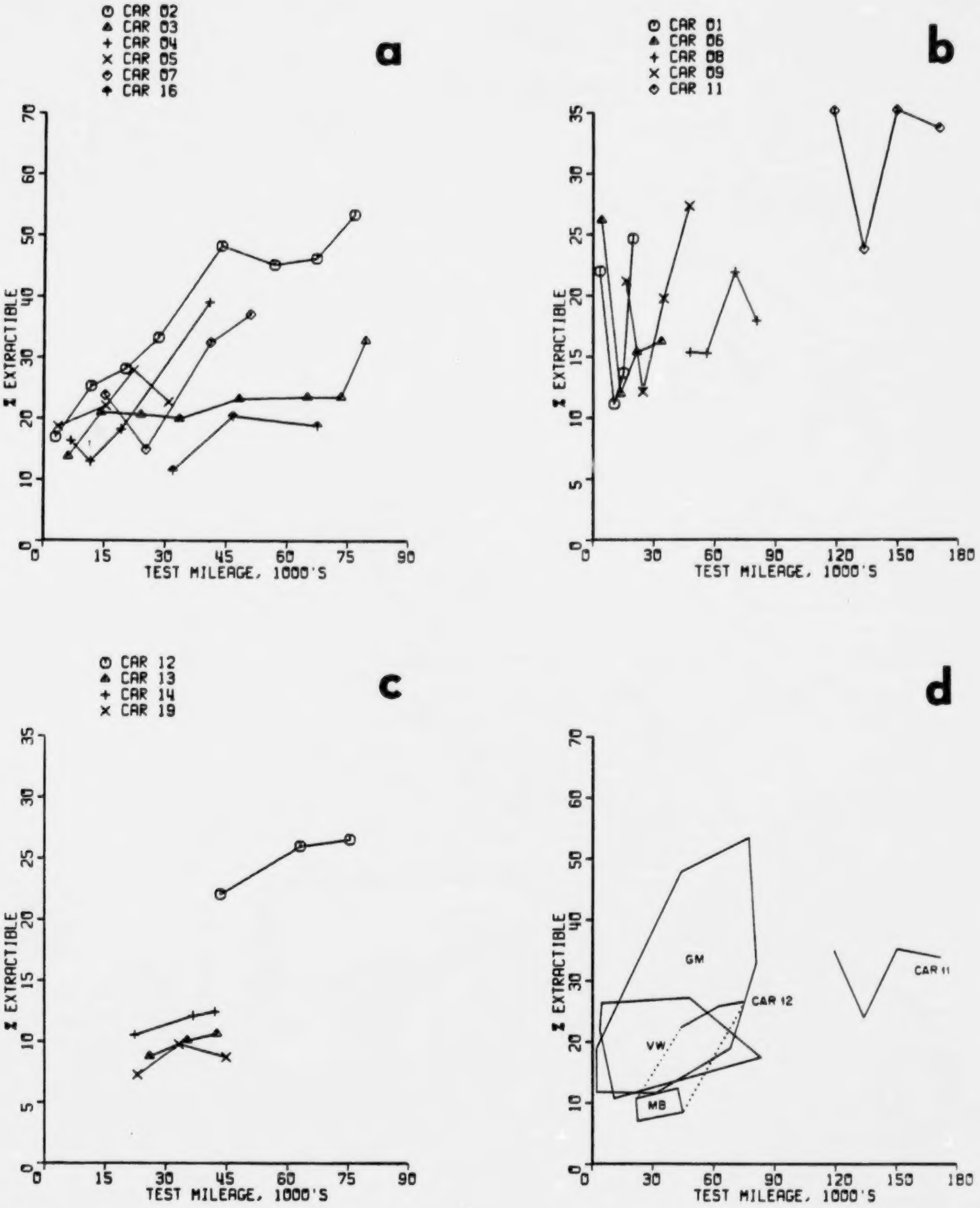


Figure 4.18 Mileage accumulation effects for FTP % extractible by vehicle group: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

Fuel Specific Emissions--

Previous discussions have expressed emissions in terms of mass per unit distance traveled, i.e., grams per mile. This section will discuss particulate, residue and extract in terms of mass per unit fuel consumed, i.e., grams per kilogram fuel (g/KgF). Fuel consumption was computed by the carbon balance method, and the weight of fuel derived from the measured specific gravity of the fuel. This method of expressing emissions permits comparisons of all groups and cycles on a common basis.

The data for fuel specific particulate, residue and extract are shown in Figures 4.19, 4.20, and 4.21 respectively. Several aspects of these figures are interesting. In Figure 4.19 there is a very large diversity in the IDLE particulate of the three vehicle groups. Figures 4.20 and 4.21 show that these differences are due mainly to changes in the residue. In fact, almost all of the variations of the particulate were due to variations of the residue. The IDLE residue for the General Motors and Mercedes-Benz groups showed a large increase relative to the other cycles but the Volkswagen group had a large decrease.

The fuel specific residue data showed the NYCC to be more comparable to IDLE than other cycles. This correspondence between the IDLE and NYCC would be expected because 40% of the NYCC time is at idle. The connection between the NYCC and IDLE has not been apparent in earlier comparisons because of the incompatibility of units.

Statistical Comparisons of Fuel Specific Emissions--

The mean fuel specific emission parameters for the FTP are segregated by group and test mileage in Table 4.8. Using the Smith-Satterthwaite test (32) for pairs of mean values, a t-statistic may be generated and tested against the null hypothesis that the data pair means were sampled from populations of equal means. For most parameters the t-statistic achieved a high significance (low α) level so that the null hypothesis could be rejected with a high degree of confidence (90% confidence or greater; α=0.100 or less). In these cases, differences observed between means were judged statistically significant. As the data were normalized to a fuel specific basis, these observations may represent real differences in fuel combustion processes among the engine types. The significance levels achieved by the t-statistic for pairs of means are given in Table 4.9.

TABLE 4.9. SIGNIFICANCE LEVEL (α LEVEL) FOR VEHICLE GROUP FUEL SPECIFIC EMISSIONS ALL MILEAGE MEANS

	HC	NO_x	CO	PART	EXT	RES	REV
GM/VW	-	.005	.005	.100	.005	-	.005
GM/MB	.005	.005	.100	.005	.005	.025	.100
VW/MB	.005	.100	.005	.005	.005	.050	.005

The differences in General Motors and Volkswagen mean fuel specific hydrocarbon emissions, over all test mileages, were not statistically significant; however, comparisons of the General Motors and Volkswagen means to the Mercedes-Benz hydrocarbon mean (considerably lower) were statistically significant. In like manner General Motors appeared significantly lower than Volkswagen and Mercedes-Benz in terms of

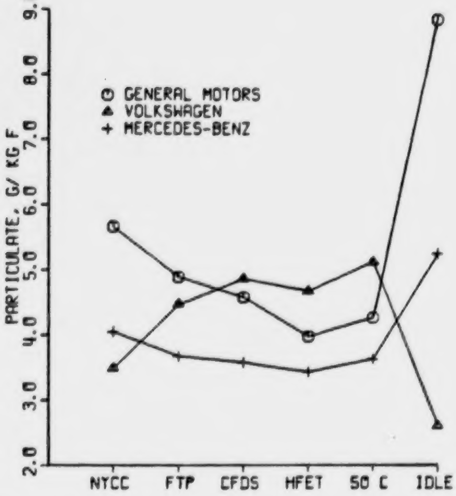


Figure 4.19 Cycle variations of fuel specific particulate by vehicle groups.

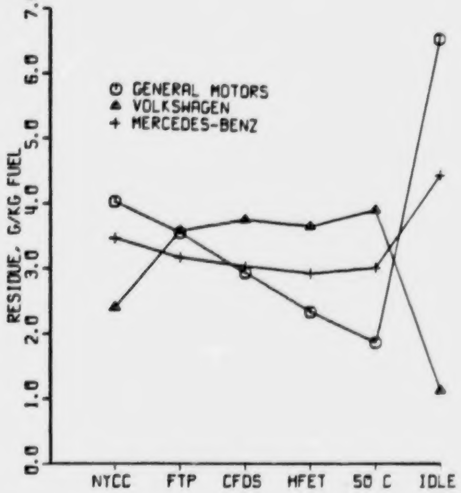


Figure 4.20 Cycle variations of fuel specific residue by vehicle groups.

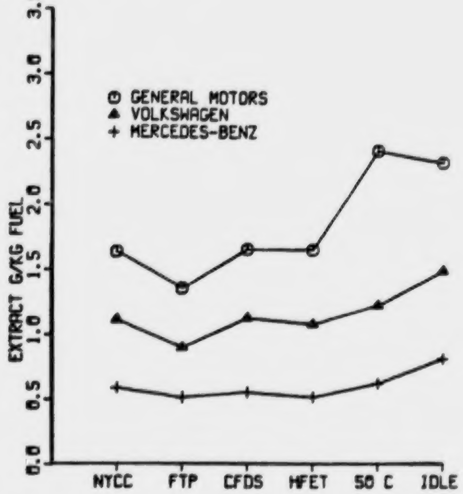


Figure 4.21 Cycle variations of fuel specific extract by vehicle groups.

TABLE 4.8. MEAN FUEL SPECIFIC EMISSION PARAMETERS BY VEHICLE GROUP AND TEST MILEAGE

		TEST MILEAGE	FTP HC G/KGF	FTP NO_x G/KGF	FTP CO G/KGF	FTP PART G/KGF	FTP EXT G/KGF	FTP RES G/KGF	FTP REV* 10^5/KGF
GM									
0-20K	N	10	9	9	9	9	9	9	9
	MEAN	10637.08	2.8832	9.8803	8.9688	4.6329	.8375	3.7954	32.9287
	STD DEV	5484.945	.3393	.7694	.8399	1.0069	.1794	.9272	18.4596
20-40K	N	8	8	8	8	8	8	8	8
	MEAN	26921.95	3.0040	9.1525	8.5552	4.5289	1.0336	3.4953	28.2102
	STD DEV	4833.605	.6831	.5831	.9686	.3536	.3850	.2192	9.0524
40-60K	N	7	7	7	7	7	7	7	6
	MEAN	46714.99	4.7219	8.9880	9.5386	5.4713	2.0042	3.4672	34.9440
	STD DEV	5666.203	1.3664	.9993	1.5307	1.4510	.9532	.7158	10.7958
ALL	N	31	30	30	30	30	30	30	28
	MEAN	34725.19	3.5959	9.2242	9.1318	4.8930	1.3539	3.5391	32.4003
	STD DEV	23175.59	1.1653	.8738	1.0982	1.0216	.8286	.6282	14.1037
VW									
0-20K	N	7	7	7	7	7	7	7	7
	MEAN	11894.82	3.1086	10.3448	12.2463	4.8342	.8941	3.9401	113.0282
	STD DEV	6110.996	.7716	.4796	2.6798	1.2060	.3989	1.0560	106.6898
20-40K	N	4	4	4	4	4	4	4	4
	MEAN	28756.64	2.8436	12.7144	12.0794	3.8587	.6097	3.2490	96.0641
	STD DEV	6664.363	.4488	3.1388	1.3967	.3203	.1183	.3410	41.0499
40-60K	N	3	3	3	3	3	3	3	2
	MEAN	50638.71	3.0633	12.4374	13.3187	4.6813	.9004	3.7809	145.4095
	STD DEV	4713.270	.7219	2.8300	1.1859	.3149	.3096	.4650	28.9461
ALL	N	20	20	20	20	19	19	19	17
	MEAN	53773.35	3.4004	11.2190	12.8973	4.4814	.9004	3.5810	100.3466
	STD DEV	51272.52	.8116	1.9612	2.0090	.8474	.3459	.7821	73.3652
MB									
0-20K	N	-	-	-	-	-	-	-	-
	MEAN	-	-	-	-	-	-	-	-
	STD DEV	-	-	-	-	-	-	-	-
20-40K	N	6	6	6	6	6	6	6	6
	MEAN	29418.33	1.2881	10.9305	7.9555	3.4617	.3396	3.1221	26.7239
	STD DEV	6385.199	.4006	.6130	1.6227	.4669	.0837	.4109	14.3987
40-60K	N	4	4	4	4	4	4	4	1
	MEAN	43193.50	2.3091	10.1387	8.6032	4.0389	.5568	3.4822	15.4572
	STD DEV	1259.243	1.0732	.6253	2.2906	.3223	.2857	.1554	-
ALL	N	12	12	12	12	12	12	12	8
	MEAN	40622.00	1.9258	10.4410	8.3430	3.6802	.5139	3.1663	24.7175
	STD DEV	15619.25	.9506	.7642	1.6790	.4505	.2787	.4083	12.8410

*Ames test with TA98(-).

fuel specific NO_x, while the Volkswagen group was significantly higher in fuel specific CO. For fuel specific particulate, Mercedes-Benz was significantly lower in mean value over all mileages. The fuel specific extract means were each significantly different from each other. The Mercedes-Benz group was significantly lower in residue, and the Volkswagen group was significantly higher in TA98 Ames activity, each on a fuel specific basis, over all mileages.

Comparisons of means at different mileage intervals did not demonstrate many statistically significant differences among the mean values, Table 4.10. General Motors group fuel specific HC emissions appeared higher in the 40-60K mile range while fuel specific NO_x appeared to decrease after 20K miles. Fuel specific extract for the General Motors group was significantly higher in the 40-60K mile range. Fuel specific particulate for the Volkswagen group was significantly lower in the 20-40K mile range. For the Mercedes-Benz group, fuel specific NO_x decreased while fuel specific particulate and residue increased significantly in the 40-60K mileage range.

TABLE 4.10. SIGNIFICANCE LEVEL (α LEVEL) FOR MEAN FUEL SPECIFIC EMISSIONS BY TEST MILEAGE RANGE

MILEAGE RANGE(Kmi)	HC	NO_x	CO	PART	EXT	RES	REV
GM							
0-20/20-40	-	0.025	-	-	-	-	-
0-20/40-60	0.010	0.050	-	-	0.010	-	-
20-40/40-60	0.010	-	.100	.100	.025	-	-
VW							
0-20/20-40	-	-	-	0.050	.100	.100	-
0-20/40-60	-	-	-	-	-	-	-
20-40/40-60	-	-	-	0.025	-	.100	.100
MB							
0-20/20-40				NO DATA			
0-20/40-60							
20-40/40-60	.100	.050	-	.025	-	.050	-

As-Received versus Control Fuel/Oil Emissions

Previous results and discussions have dealt exclusively with Phase 3, where control diesel fuel and fresh manufacturer specified lubricating oil were used in all vehicles. The "as-received" fuel test condition was usually similar to the control condition, with the notable exception of the winter season when gasoline, kerosene and other additives were commonly combined with diesel fuel. Analyses of as-received and control (AEL) fuels are given in Appendix C. While the difference between Phase 1 and Phase 3 might be expected to be quite small for regulated emissions, the effects on particulate, residue, extract and bioassay characterization were unknown and considered to be potentially greater.

A first approach to examining the data base for emission differences between phases was to form a ratio of emission results from Phase 1 to those of Phase 3 for each specific vehicle test cycle and emissions parameter. These ratios were then grouped by manufacturer, and Table 4.11 gives the average of these phase ratios and the associated coefficients of variation (CV). Bioassay data are found in Table 6.2. The phase ratios are, with few exceptions, very close to unity. This suggests little average effect of the fuel/oil changes between Phases 1 and 3.

TABLE 4.II. RATIO OF PHASE 1 EMISSIONS TO PHASE 3 EMISSIONS

		HC	CO	NO_x	MPG	PART	EXT	RES
GM	MEAN	.9369	.9741	1.0238	1.0014	.9888	.9386	1.0343
	CV%	54.85	8.71	5.95	4.61	17.56	28.88	18.32
VW	MEAN	1.0402	1.0412	.9901	.9933	1.0477	1.1464	1.0538
	CV%	30.08	16.03	6.13	5.10	19.90	73.25	42.67
MB	MEAN	.8309	.9455	1.0000	1.0080	.9884	1.0459	.9828
	CV%	25.09	10.62	7.17	6.91	13.69	19.14	14.41
OTHER	MEAN	1.0726	1.0313	.9888	.9992	1.0287	1.1158	1.0244
	CV%	30.84	14.79	9.90	4.74	20.75	28.45	28.15

The Mercedes-Benz group hydrocarbon data and the Volkswagen and "other" group extract data exhibit the most pronounced Phase 1 to Phase 3 differences. No explanation can be given for these findings until further analysis of the collected fuel and oil samples are performed.

The CV values for HC were much higher than any other gaseous parameter, and at least some of this resulted from the seasonal fuel variation mentioned above. The CV values for particulate, extract and residue were in the 13-29% range, except for the Volkswagen group with significantly higher CV values for extract and residue. The magnitude of these CV values suggests that there are significant individual changes between phases. The CV values found for repeated particulate measurements reported elsewhere in this report are about 6%, and were much less than the phase ratio values. Thus some, but not all, of the phase ratio CV was due to measurement uncertainty. A more detailed fuel/oil correlation analysis will be required to further define the basis for the observed emission changes between "as-received" and "control" test conditions.

Emission Changes Between Successive Tests

This section describes the changes observed in various emission parameters between successive tests. The average interval between tests was about 12,000 miles, with a standard deviation of ±5,000 miles for all tests. Also the mileages bounded by the first and last test of the sample group vehicles were not uniform. These factors make the computation of emissions change with accumulated miles a difficult concept to establish for all cars on a common basis. The new-car certification definition of emissions deterioration could thus not be applied to these vehicles. Furthermore, the emission changes between successive tests on these in-use vehicles frequently changed in response to factors other than mileage accumulation *per se*, and using mileage accumulation as a singular regression variable was not found to give an accurate representation of the emission changes observed. Engine mechanical work, injection timing, adjustments, etc. were often more dominant uncontrolled factors causing larger emission changes than those caused by accumulated mileage between successive tests. It was recognized, however, that the in-use data base could be used to provide indications of emissions changes between successive tests on in-use vehicles over periods of mileage accumulation.

A simple method of representing emission-mileage effects was to present the absolute value of the emission parameters as measured at increasing mileage for each vehicle. This was an obviously useful approach for certain applications, and tables and figures of this type are presented in the Mileage Accumulation Effects portion of this section. An alternate method of comparison was developed which describes the change in emissions as a percentage of the emission at the first test of any two-test interval. Expressing the emission change as a percentage of the previous test value, the absolute emissions level was removed, making direct comparisons among high and low emission vehicles possible. To account for the variation in test interval mileage, the change in emissions between any two successive tests was normalized to a 10,000 mile basis. The factor which was adopted for the following comparisons was thus the change in emissions between any two successive tests, expressed as a percentage of the emissions level of the first of the two tests in question, normalized to a 10,000 mile basis, or %V. Thus we define:

$$\%V = \frac{(X_1 - X_o) \quad 10^6}{(X_o) \ (M_1 - M_o)}$$

where: X_1 = emission value at current test
X_o = emission value at previous test
M_1 = vehicle mileage at current test
M_o = vehicle mileage at previous test

The project data base was processed to provide these %V values for the FTP and HFET cycles. For vehicles with n total tests at different mileage accumulation points, this resulted in n-1 matrices of emission change values. The FTP %V data are given in Table 4.12.

While these computations could be carried out for all specific test cycles in each test, the summary results in the form of distribution curves are shown for only the FTP and HFET cycles in Figures 4.22-4.25. The %V values are both positive and negative, indicating increases and decreases in emissions between successive tests. When all change values are averaged, the mean provides a rough indication of long-term changes with accumulated miles.

This computation and data presentation framework does not represent all that could be done with project data to address the question of changes with mileage, but does provide a first view of the data from the project in terms of changes as they were observed.

Figure 4.22 gives the FTP Phase 3 frequency distributions for HC, CO, NO_x, and MPG. The %V mean value and CV are given for each distribution. Smoothed distributions are shown rather than discrete data to facilitate visual comparisons among parameters. Figure 4.23 gives the same type of frequency distribution for particulate, residue, and extract for the FTP. Figures 4.24 and 4.25 give the same data presentations as Figures 4.22 and 4.23, except the results are for the HFET. Both HFET and FTP plots for corresponding emissions parameters are very similar. In Figures 4.23 and 4.25, the extract exhibits a larger degree of variation than the residue, with the total particulate between these values being a composite of both.

As a result of the smoothing of discrete data in Figures 4.22-4.25, the distribution curve mean given in the figure may be somewhat different than the true data mean given in the upper left of each figure. Furthermore, the data sets from which the distributions were obtained included all project test vehicles and all test intervals. Segregation of the data by vehicle manufacturer type could reveal

TABLE 4.12. FTP %V BY VEHICLE GROUP AND TEST MILEAGE RANGE

CAR GROUP	MIDPT MILEAGE RANGE*		HC	NO_x	CO	FUEL MPG	PT	EXT	RES	% EXT	REV / ug PT	REV / ug EXT
GM	0-20 K	n	8	8	8	8	8	8	8	8	8	8
		x	8.4	-0.6	4.7	-1.5	11.4	35.1	6.4	24.9	7.5	-0.3
		σ	18.3	15.4	9.4	6.0	18.4	25.4	24.0	36.8	88.9	94.6
	20-40 K	n	7	7	7	7	8	8	8	8	8	8
		x	29.9	1.3	0.9	0.6	9.0	32.0	4.3	21.1	8.0	-6.8
		σ	26.3	5.5	8.0	1.6	10.0	41.0	17.6	39.0	56.9	38.6
	40-60 K	n	5	5	5	5	5	5	5	5	4	4
		x	-0.7	-3.6	7.9	2.0	3.4	7.0	2.5	3.6	34.6	31.5
		σ	12.7	6.1	7.5	4.1	8.7	12.6	10.3	8.8	54.0	43.2
	ALL	n	24	24	24	24	25	25	25	25	23	23
		x	14.3	-1.0	3.8	0.4	7.9	27.4	3.0	18.8	9.2	0.3
		σ	25.7	9.5	8.7	4.5	14.0	34.4	17.4	32.1	64.8	62.4
VW	0-20 K	n	5	5	5	5	5	5	5	5	5	5
		x	0.0	-5.2	12.8	3.7	5.8	24.7	8.1	26.0	195.5	277.5
		σ	48.6	5.0	57.5	5.1	55.8	111.7	69.6	98.2	179.0	298.2
	20-40 K	n	3	3	3	3	3	3	3	3	3	3
		x	-6.5	17.5	2.9	0.8	16.4	9.3	20.8	4.6	297.9	562.4
		σ	5.8	36.3	20.7	5.1	43.3	31.3	58.2	56.1	586.4	1065.0
	40-60 K	n	2	2	2	2	2	2	2	2	1	1
		x	-14.9	6.0	2.6	0.2	15.2	31.4	11.2	14.6	20.8	21.7
		σ	10.4	9.4	5.3	5.3	9.5	14.6	15.4	21.7	-	-
	ALL	n	15	15	15	15	14	14	14	15	13	13
		x	-1.4	3.5	6.3	1.8	6.7	16.9	7.4	12.8	141.0	232.3
		σ	28.6	16.6	32.2	5.2	37.0	65.4	46.8	59.4	291.3	521.3
MB	0-20 K	n										
		x	NO DATA									
		σ										
	20-40 K	n	6	6	6	6	6	6	6	6	3	3
		x	19.9	-11.2	-7.5	8.7	-0.7	7.7	-1.5	10.6	36.4	17.2
		σ	32.0	9.5	10.2	11.0	22.2	14.1	23.1	14.2	63.6	60.9
	40-60 K	n	1	1	1	1	1	1	1	1	1	1
		x	-9.0	-.04	-5.1	-0.7	-9.5	-2.1	-11.6	9.1	39.2	25.6
		σ	-	-	-	-	-	-	-	-	-	-
	ALL	n	8	8	8	8	8	8	8	8	4	4
		x	13.5	-9.1	-7.7	7.5	-2.1	5.3	-3.1	9.3	37.1	19.3
		σ	29.6	9.1	8.8	9.9	19.1	12.7	19.9	12.4	51.9	49.9
ALL	0-20 K	n	14	14	14	14	14	14	14	14	14	14
		x	5.3	-2.4	7.9	0.0	9.8	30.8	6.6	24.1	71.2	95.7
		σ	30.4	11.8	32.9	6.1	33.9	64.9	42.5	60.9	153.3	228.2
	20-40 K	n	19	19	19	19	20	20	20	20	16	16
		x	14.9	-0.2	-1.7	4.3	6.8	17.3	5.8	11.6	78.0	121.1
		σ	29.8	18.2	13.1	7.5	23.9	35.4	26.5	32.9	249.7	452.3
	40-60 K	n	12	12	12	12	12	12	12	12	10	10
		x	1.7	0.3	6.9	0.5	6.4	11.4	5.2	4.8	20.6	17.5
		σ	17.0	6.5	11.8	4.1	11.3	20.2	13.7	15.0	40.1	30.2
	ALL	n	58	58	58	58	58	58	58	59	49	48
		x	8.8	-1.0	2.9	2.1	5.9	19.2	3.4	13.7	47.7	67.5
		σ	26.4	12.3	19.1	6.2	22.9	42.1	27.0	37.8	166.5	288.5

*The midpoint odometer mileage between successive vehicle tests.

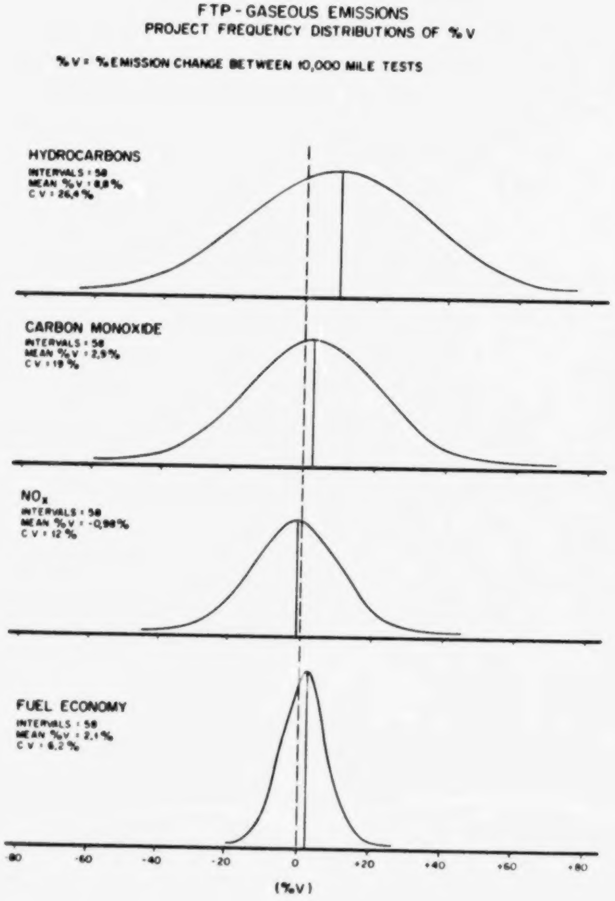


Figure 4.22 Frequency distributions of %V for FTP gaseous parameters.

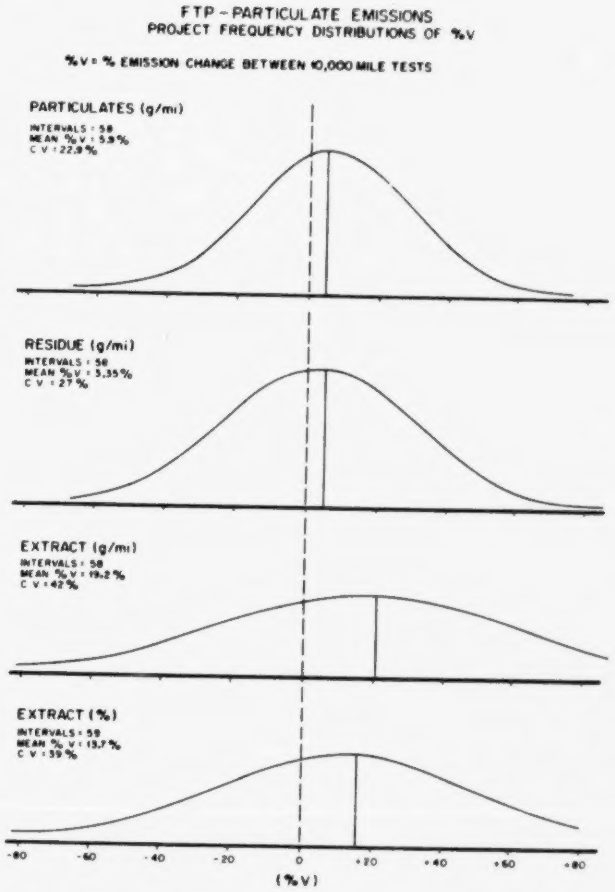


Figure 4.23 Frequency distributions of %V for FTP particulate parameters.

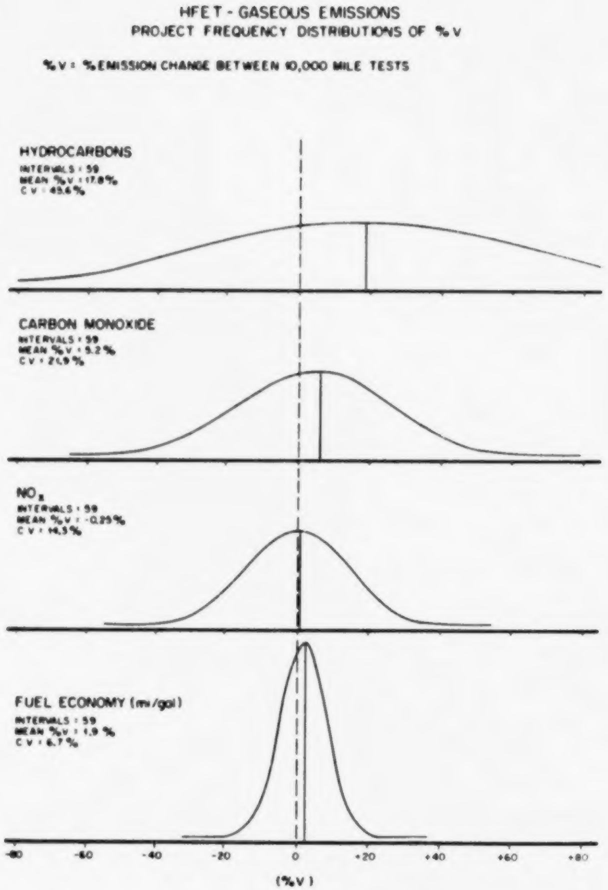


Figure 4.24 Frequency distributions of %V for HFET gaseous parameters.

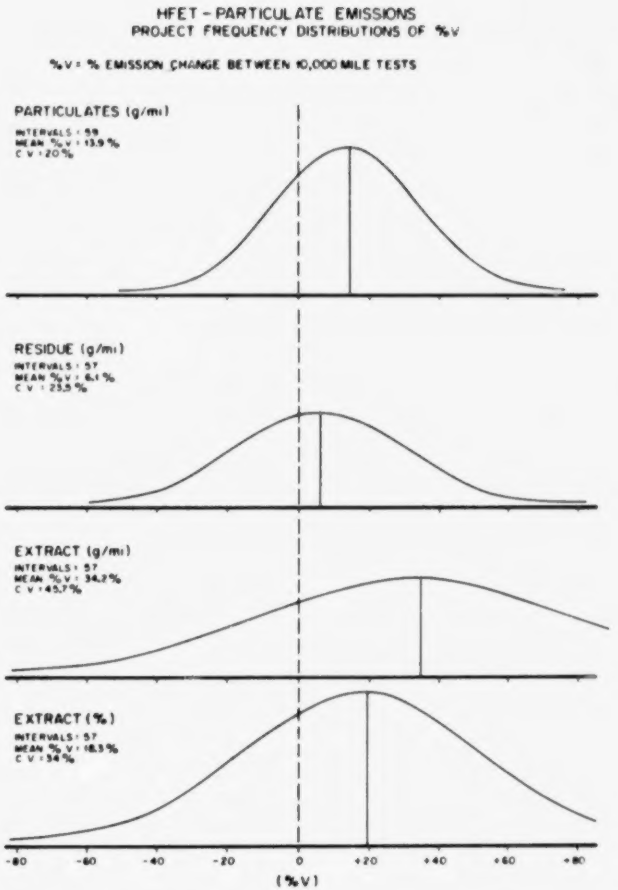


Figure 4.25 Frequency distributions of %V for HFET particulate parameters.

differences not apparent in the overall grouping presented here.

Statistical Tests on %V--

The general parameter, %V, has been previously defined as the change in a vehicle emission parameter between two successive tests, calculated on a 10,000 mile basis. The %V is, effectively, a deterioration rate (assuming that emissions are increasing) in relative (taken as a percentage increase from the last test) rather than absolute terms. These parameters may, therefore, be used in a comparative manner to examine mileage accumulation effects or vehicle group differences.

One method to compare deterioration rates against mileage accumulation levels was to test for statistically significant differences among the means at each mileage level. From Table 4.12, means were tested pairwise using the Smith-Satterwaite t-test (32) and an "equal population means" null hypothesis. For example, within the General Motors group, the mean deterioration rate, %V, for HC is highest in the 20,000 to 40,000 (20-40K) mile range. The difference between the %V mean in the 0-20K and 20-40K ranges was judged statistically significant since the t-statistic for this data pair leads to the rejection of the null hypothesis at the 95% confidence (α=0.05) level. Similarly the General Motors group %V HC means at 20-40K and 40-60K miles were judged to be unequal at the 97.5% confidence (α = 0.025) level. The difference in %V HC means at the 0-20K and 40-60K levels was not judged to be statistically significant as the t-statistic α-level was greater than 0.100 (less than 90% confidence rejection of null hypothesis). Table 4.13 gives the α-levels which were achieved by the t-statistic for pairs of means: α-levels in excess of 0.100 (α=0.100 was considered marginally significant) are not listed individually in the table but are represented by a dash. There were insufficient data for statistical comparison of %V means at mileage levels in the Mercedes-Benz group.

TABLE 4.13. SIGNIFICANCE LEVEL (α LEVEL) FOR DIFFERENCES IN %V MEANS BY MILEAGE RANGE AND BETWEEN VEHICLE GROUPS

VEHICLE GROUP & MILEAGE LEVEL (1000 MILES)	HC	NO_X	CO	FUEL MPG	PART	EXT	RES	% EXT	REV/ µg P	REV/ µg EXT
GM										
0-20/20-40	.050	-	-	-	-	-	-	-	-	-
0-20/40-60	-	-	-	-	-	.025	-	.100	-	-
20-40/40-60	.025	.100	.100	-	-	.100	-	-	-	.100
VW										
0-20/20-40	-	-	-	-	-	-	-	-	-	-
0-20/40-60	-	-	-	-	-	-	-	-	-	-
20-40/40-60	-	-	-	-	-	-	-	-	-	-
ALL MILEAGE LEVELS										
GM/VW	.050	-	-	-	-	-	-	-	.100	.100
GM/MB	-	.025	.005	.050	-	.005	-	-	-	-
VW/MB	-	.025	.100	.100	-	-	-	-	-	.100

In Table 4.12, standard deviations on the order of or in excess of mean values are frequently observed. This degree of scatter in the data was a major factor in the low level of statistical significance among data pairs reported in Table 4.13, and is especially evident in the VW %V data. Nonetheless, some differences appeared to be significant: GM %V for HC at 0-20/20-40K and 20-40/40-60K miles; GM %V for extract at 0-20/40-60K miles; GM/VW %V for HC; GM and VW/MB %V for NO_x; GM/MB %V for CO; GM/MB %V for fuel economy; and GM/MB %V for extract.

This analysis has relevance in estimation of emission deterioration factors and the rate of deterioration with mileage accumulation. Comparison among vehicle groups may also be made. The basis of comparison, however, is the % change in successive tests, a relative measure, rather than absolute changes such as presented in Figures 4.11-4.18.

Non-Volatile Hydrocarbons (NVHC)--

The HFID (heated flame ionization detector) measurement of gaseous hydrocarbon emissions includes any hydrocarbons associated with the particulate matter that volatilize in the hot filter (190°C) in the HFID probe system. The particle-bound HC may not all volatilize at 190°C, but work by Cuthbertson et. al. (33) confirms that most of these HC species will not remain in the hot filter under these conditions.

The solvent extraction of particulate laden filters also provides a measure of the particle-bound hydrocarbons, and although this measure may not represent an absolute measure of particle-bound HC, a carefully performed extract determination is the most consistent indicator in this study for particle-bound HC mass.

The solvent derived extract provides, in comparison with the HFID measurements, an approximate indication of how much of the HFID mass could be resulting from the volatilization of particle-bound hydrocarbons in the 190°C hot filter. The non-volatile hydrocarbons (NVHC) term is thus defined as:

$$\text{NVHC}(\%) = \frac{\text{Solvent Derived Extract HC} \times 100}{\text{HFID reported HC}}$$

NVHC is the percentage of the HFID value that could reasonably be expected to be resulting from particle-bound HC volatilization as compared to dilute exhaust (gas-phase) HC components.

Manufacturer group average results for the various test cycles are shown in Figure 4.26. For all groups the higher speed cycles tend to exhibit higher percentage values of non-volatile hydrocarbons. Mileage accumulation effects on NVHC are shown for individual vehicles within each manufacturer group in Figure 4.27 a-d. The data from four test cycles were averaged at each vehicle test to obtain a four-cycle average (FTP, CFDS, HFET, 50C) parameter for mileage accumulation plots. The mileage accumulation trend for the General Motors group is more consistent than for the Volkswagen group. The Volkswagen group exhibits both increasing and decreasing trends, whereas most other sample group vehicles showed an increase in NVHC with increased mileage accumulation. This indicates that increases in total hydrocarbon emissions with vehicle age were due more to increases in particulate extract than to gas phase hydrocarbons. However, these results must be considered in the context of the dilution tunnel where they were measured, and the interaction of particulate/gas phase hydrocarbons may not be the same as for direct atmospheric emission.

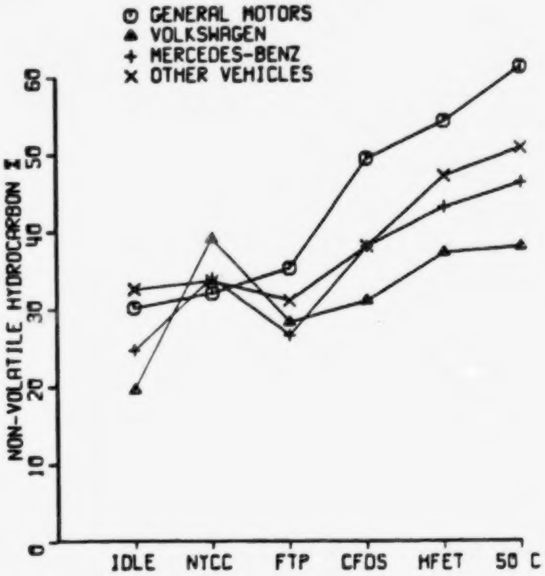


Figure 4.26 Cycle variations of non-volatile hydrocarbons by vehicle groups.

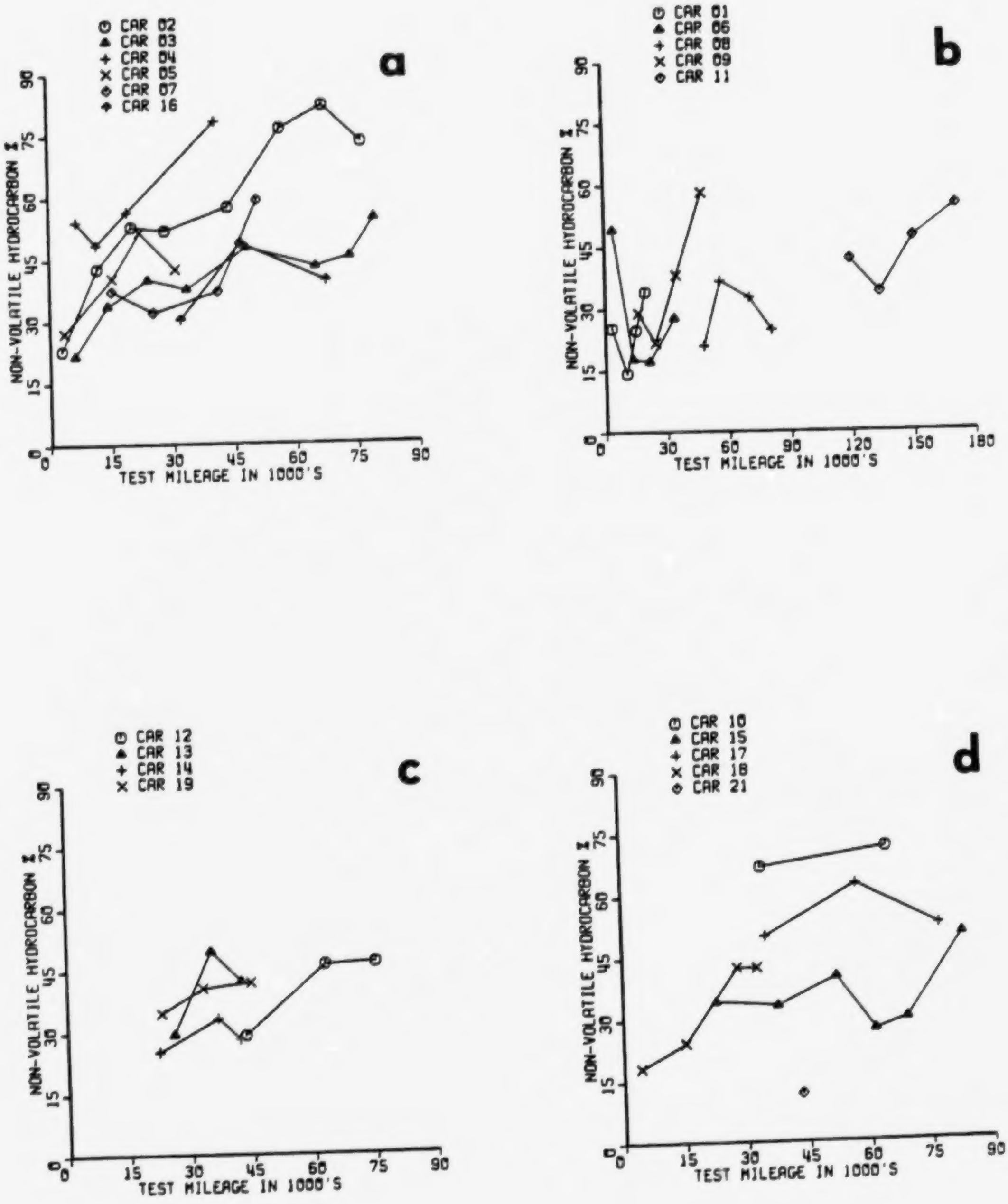


Figure 4.27 Mileage accumulation effects for average of FTP, CFDS, HFET and 50C non-volatile hydrocarbons by vehicle groups: (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) other vehicles.

SECTION 5

FUEL ECONOMY

INTRODUCTION

The project was designed to permit up to three independent measures of vehicle fuel economy. As part of the laboratory emissions testing carbon balance fuel consumption, in accordance with EPA certification procedure, was measured for each test cycle. In addition, each vehicle was outfitted with under-hood flow totalizing meters and an engine hour meter. Two fuel meters were used on each vehicle to measure fuel flow into and from the injection system, thus permitting calculation of fuel consumed between tests by subtraction. For the two loan vehicles (Car #1 and Car #5), fuel and engine hour meter readings were recorded at each fueling to obtain fuel economy and average speed data for each tank fill.

Fuel economy by the carbon balance method was determined for the FTP, CFDS and HFET for the first 34 tests and for the FTP, CFDS, HFET, 50C, NYCC and IDLE for the last 46 tests. The data presented in this section are for Phase 3 only. In addition to the data presented here, group averages with standard deviations can also be found in Tables 4.1 through 4.6. Table A-18 in Appendix A gives individual vehicle averages and the corresponding Phase 1 data are given in Table A-17. These tables also give the fuel economy of the individual bags of the FTP.

CYCLE VARIATIONS OF FUEL ECONOMY

In Figure 5.1 the carbon balance fuel economy of the General Motors, Volkswagen, and Mercedes-Benz groups are presented for the various test cycles. Figure 5.2 gives the same data in units of ton-mile/gallon to normalize fuel consumption by vehicle test weight. In terms of ton-mile/gallon the General Motors group had slightly higher fuel economy than the Volkswagen and Mercedes-Benz groups at the 50C, but exhibited a significant penalty for low speed test cycles with large speed variability. All three vehicle groups exhibit essentially two distinct regions on either side of the CFDS test cycle, which may be related to lower speed operation at lower transmission gear ratios.

MILEAGE ACCUMULATION EFFECTS ON FUEL ECONOMY

Fuel economy in miles per gallon as determined by the carbon balance method is shown for the individual vehicles in Figures 5.3a, b, and c and for the groups together in Figure 5.3d. All data are the Phase 3 FTP. The General Motors group shows no mileage accumulation effects either for single vehicles or for the group as a whole. The 30 tests on six vehicles over a 75,000 mile interval range from 18.2 to 21.8 mpg

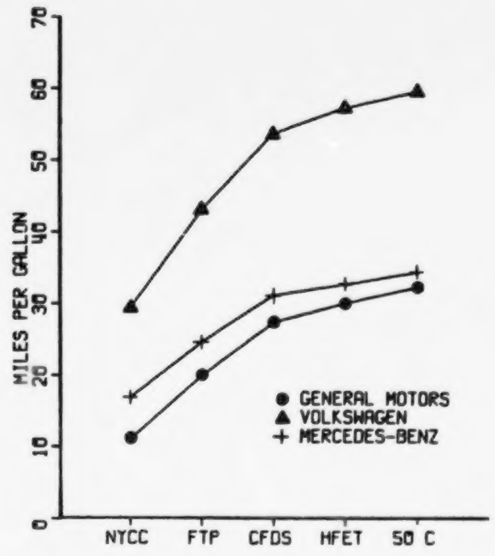


Figure 5.1 Cycle variations of fuel economy, miles/gallon, by vehicle group.

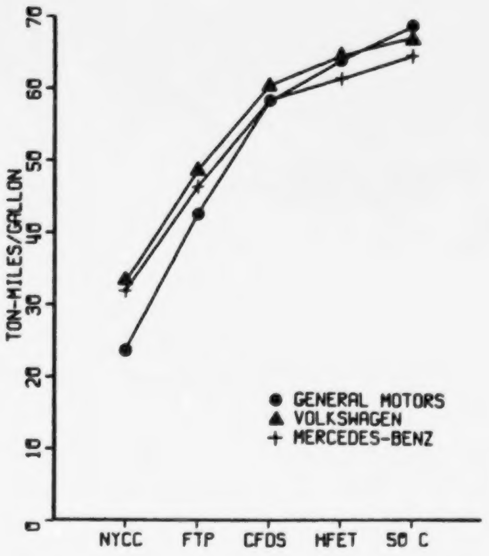


Figure 5.2 Cycle variations of fuel economy, ton-mile/gallon, by vehicle group.

with an average of 20.0±1.0 mpg. The Volkswagen group has fuel economy substantially higher than either the General Motors or Mercedes-Benz group. On a mpg (absolute) basis these variations are similar to those of Mercedes-Benz but on a relative scale they show less scatter because of the higher fuel economies. All five vehicles have higher fuel economy than any other vehicles. Some vehicles show fuel economy increases with increased mileage but no overall trend is apparent. Car #6, the only vehicle in the group with a 5-speed transmission had an average fuel economy of 43.7 mpg compared to 43.0 mpg for the 4-speed models. (The advantage of the 5-speed transmission was more apparent in the HFET data where the 5-speed average fuel economy was 61.8 mpg versus 56.4 for the 4-speed transmission models. See Appendix A, Table A-18.)

The Mercedes-Benz group of Figure 5.3c have a range of fuel economies from 20.9 to 28.9 mpg with an average of 24.7±2.2 mpg. Variations for individual vehicles are larger than for the General Motors groups and display a trend of increased fuel economy at higher mileages.

The composite of the vehicle groups in Figure 5.3d shows the data sets to be almost mutually exclusive and following the order GM < MB << VW. Part of the variation in the Volkswagen group is probably due to the mix of model years and transmissions while the Mercedes-Benz group contains vehicles of different years, models, engines and transmissions.

OVER-THE-ROAD FUEL ECONOMY

The fuel meters were positive displacement type totalizing meters (Servis Recorder Company) with a volumetric accuracy of ±1%. Fuel measurements were not compensated for temperature variation, and distance traveled was determined from

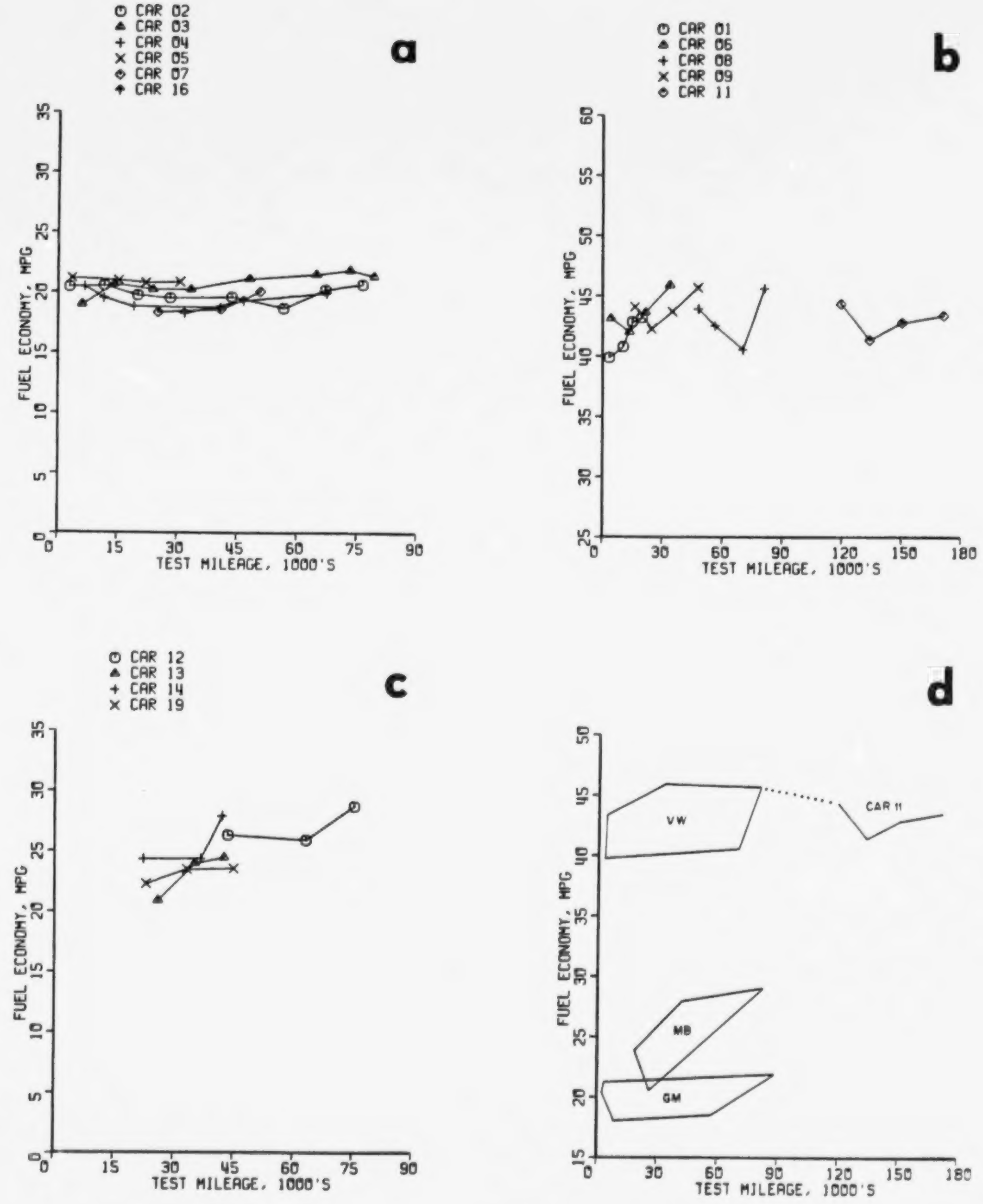


Figure 5.3 Mileage accumulation effects for FTP fuel economy, mpg, for (a) General Motors group, (b) Volkswagen group, (c) Mercedes-Benz group, (d) all three groups.

the vehicle odometer. Therefore, the overall fuel economy and vehicle speed data were less accurate than would have been possible with research grade instrumentation. The basic intent of these meter installations was to obtain data that corresponded to those which a vehicle owner would obtain based on tank-fill records. For this purpose the meter installations were very satisfactory. This point is demonstrated by the meter records for Car #1 and Car #5 as compared to fuel log book data. These data, collected over approximately 50,000 total miles of vehicle usage differed by 1.6% between the meter and tank-fill data. Table 5.1 gives the over-the-road fuel economy and vehicle speed data obtained between vehicle tests by the underhood meters for each vehicle in the sample group.

Figure 5.4 gives the over-the-road fuel economy and vehicle speed results for individual tank-fills as determined from the underhood meters for Car #1. The smooth line connects the laboratory carbon-balance fuel economy results for this vehicle. At all average speeds, the carbon balance fuel economy was higher than meter fuel economy. Figure 5.4 also contains the frequency distributions of fuel economy and average speed from underhood meters and vehicle odometer/hour meter. Car #1 was used frequently for short trips and around-the-town driving. Its average speed was about 30 mph. The 32 data points are evenly distributed about the FTP laboratory fuel economy value. The CFDS laboratory value is an upper limit for the fuel economy. The carbon balance fuel economy for the FTP, a cycle with a lower average speed than most of the over-the-road data, best approximated the average over-the-road fuel economy. The FTP was, therefore, the best laboratory fuel economy indicator of in-use fuel economy for this vehicle. A similar conclusion was reached in an earlier in-use study of 56 catalyst-equipped cars from this geographic area (34). Of course, the over-the-road data include many factors not specifically accounted for in controlled laboratory testing, such as road variations, hills, snow and slush, payload, etc.

Figure 5.5 gives results for over-the-road and carbon balance fuel economy measurements for Car #5 in the format described above. Car #5 was frequently used for long, high-speed trips as evidenced by the number of average speeds above 40 mph. The average overall speed was about 35 mph. In this case about 75% of the over-the-road fuel economy exceeds the FTP but only one value exceeds the CFDS. The FTP was still the best laboratory fuel economy indicator for actual in-use economy.

Figure 5.6 gives results in the same format as Figures 5.4 and 5.5, except that the over-the-road data presented are for the General Motors group between tests in contrast to the tank-fill data of Figures 5.4 and 5.5. Each data point now represents 5-10,000 miles of vehicle use. The carbon balance results are now the average of all tests for all General Motors group vehicles. The same general conclusions were evident for these data as from the previous results for individual tank fills on single vehicles.

TABLE 5.1. FUEL ECONOMY AND VEHICLE SPEED FROM UNDERHOOD METERS

CAR #	MAKE YEAR	MODEL	ENGINE DISP. (liters)	TRANS-MISSION		DATA FOR TEST INTERVALS						
1	VW 79	RABBIT	1.5	M4	MPG	43.2	-	42.7				
					MPH	31.3	-	28.2				
2	OLDS 79	CUTLASS CRUISER	5.7	A3	MPG	-	26.5	-	32.4	15.0	19.2	17.9
					MPH	42.9	44.8	44.3	44.8	45.1	45.5	50.3
3	OLDS 79	CUTLASS CRUISER	5.7	A3	MPG	23.8	24.4	25.8	23.0	-	23.4	16.8
					MPH	38.8	41.8	43.6	39.0	40.1	39.8	29.7
4	OLDS 79	98 REGENCY	5.7	A3	MPG	17.1	14.2	21.1				
					MPH	16.9	13.7	39.5				
5	OLDS 79	CUTLASS CRUISER	5.7	A3	MPG	24.3	23.1	-				
					MPH	35.1	35.3	34.7				
6	VW 80	RABBIT	1.5	M5	MPG	46.4	42.9	46.5				
					MPH	33.9	32.7	32.8				
7	CADILLAC 79	ELDORADO	5.7	A3	MPG	20.2	-	19.5				
					MPH	28.3	28.5	27.0				
8	VW 78	RABBIT	1.5	M4	MPG	-	-	-				
					MPH	36.8	35.6	37.6				
9	VW 79	RABBIT	1.5	M4	MPG	42.2	37.2	41.1				
					MPH	31.5	29.6	32.3				
10	DODGE 78	D-10	4.0	A3	MPG	17.0						
					MPH	28.2						
11	VW 77	RABBIT	1.5	M4	MPG	42.6	40.0	-				
					MPH	45.0	34.9	41.0				
12	MB 77	240D	2.4	M4	MPG	-	-	-				
					MPH	36.8	38.1					
13	MB 78	300CD	3.0	A4	MPG	23.0	26.6					
					MPH	29.4	28.0					
14	MB 79	240D	2.4	M4	MPG	-	29.4					
					MPH	33.8	28.6					
15	AUDI 79	5000	2.0	M5	MPG	34.6	31.0	31.3	-	-		
					MPH	38.0	33.6	-	39.7	36.5		
16	OLDS 79	DELTA 88	5.7	A3	MPG	-	21.5					
					MPH	32.2	32.9					
17	PEUGEOT 79	504	2.3	M4	MPG	31.7	30.0					
					MPH	40.8	40.2					
18	OLDS 80	CUTLASS CRUISER	5.7	A3	MPG	-	-	-				
					MPH	59.8	33.7	30.7				

Note: No meters were installed on Cars # 19, 20, 21; missing data implies defective meter operation.

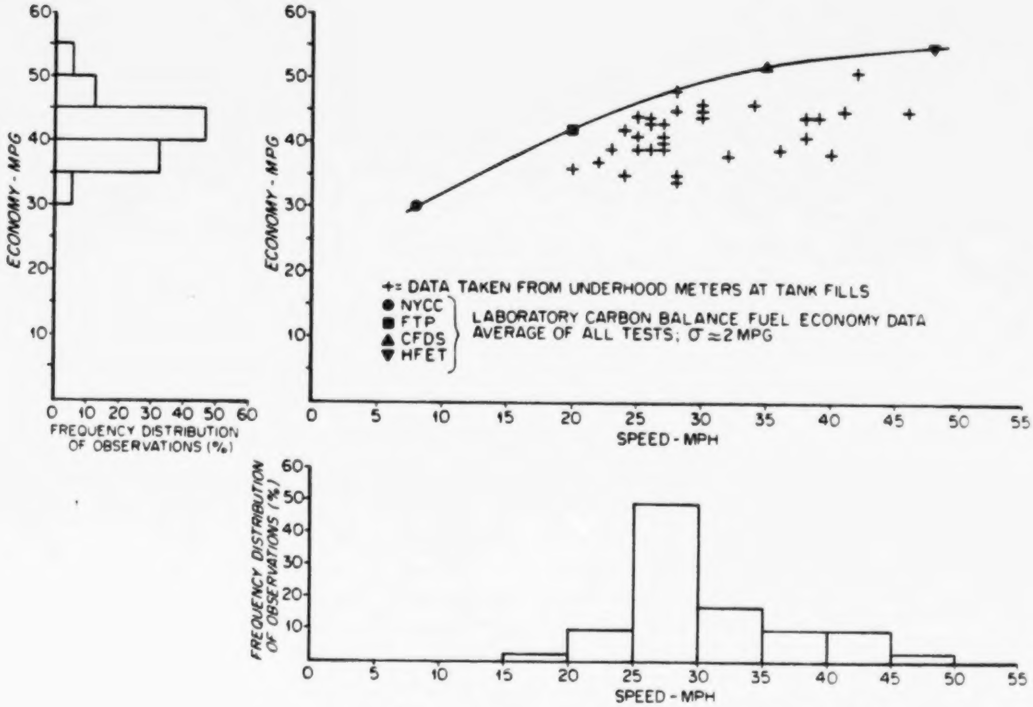


Figure 5.4 Over-the-road fuel economy vs. speed for Car #1.

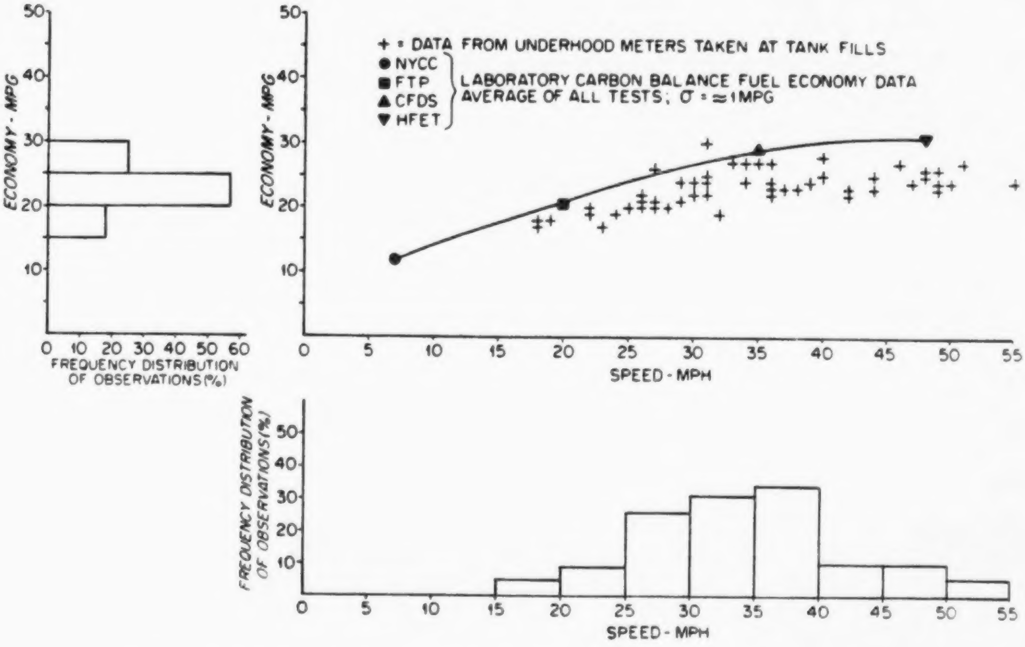


Figure 5.5 Over-the-road fuel economy vs. speed for Car #5.

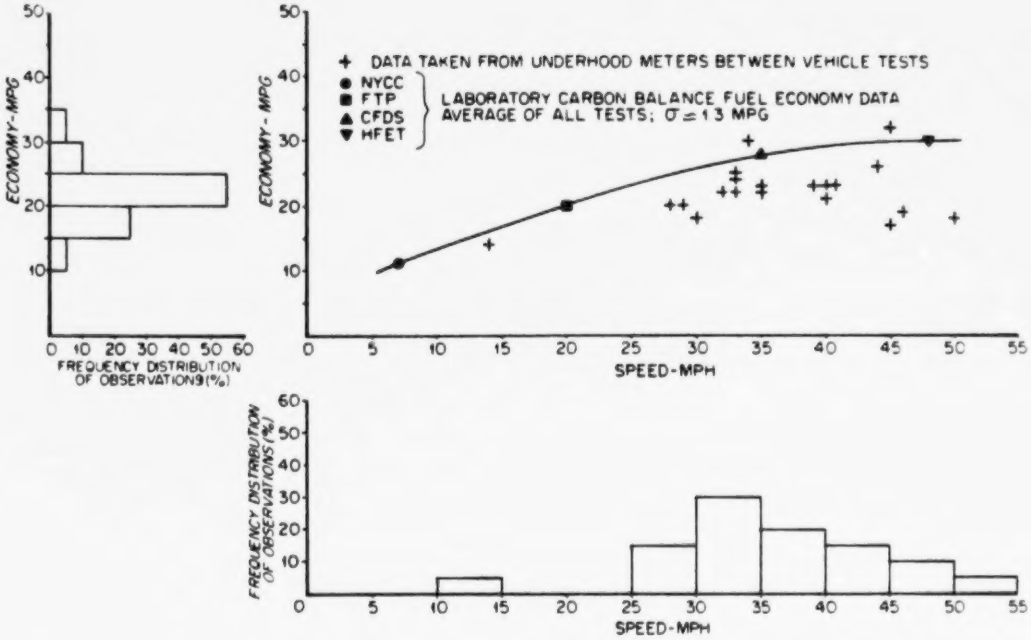


Figure 5.6 Over-the-road fuel economy vs. speed for General Motors group.

SECTION 6

BIOASSAY CHARACTERIZATION

GENERAL METHODOLOGY

Extract samples from the 50 cm x 50 cm filters were individually tested for extract dose/response potency by the Ames Salmonella typhimurium/microsome method with tester strain TA98, without metabolic activation (TA98-). Tester strains other than TA98 were used, and assays with metabolic activation were also performed. However, these assays were mainly applied to those special samples subjected to detailed chemical analysis and these data are included in Section 8 dealing with chemical characterization of extracts. A detailed description of the entire assay protocol will not be presented here, except to note that protocol guidelines specified by Ames (35) and modified by deSerres and Shelly (36) were followed unless specifically noted. Certain other procedural aspects of the assay will be described since these may provide insight to the TA98(-) assay as applied to the over 1100 extract samples of the in-use diesel portion of the project.

The solvent-free extracts which were stored at -80°C were redissolved in 75% dichloromethane, 25% acetone and split into two portions. One portion was redried and returned to freezer archive storage. The other portion was redried, weighed and redissolved in DMSO for the bioassay. Duplicate plates were run at extract doses of 0, 10, 20, 30, 40, 50, 75, 100, and 200 µg. The raw data from each plate count (Biotran Model C-111) were entered into the computer from which a data plot was obtained. The data were fitted to several straight line regressions utilizing first, all the data, and subsequently with the 200 µg dose data eliminated from the regression, and then with the 200 and 100 µg doses eliminated, etc. Summary results for each regression were printed on the display plot. Three typical examples of these regression/plot outputs are shown in Appendix B. Judgement was frequently needed to select the "best" slope of the dose/response curve by examination of the raw data, comparison of different regression fits, R^2 values, intercept of the fitted line, etc. This judgement was not absolute or unequivocal but was applied consistently to obtain a slope (revertants/µg dose of extract). R^2 values were typically greater than 0.90 and usually the highest dose of the regression line was 50, 75 or 100 µg. 12-16 individual raw plate counts were typically used to determine the slope.

BIOASSAY STANDARDIZATION

Application of the Ames bioassay to a mileage accumulation study of diesel emissions was an extension of the assay beyond past applications. In this study, we attempted to compare assay data in a semi-quantitative manner from the same vehicles over a 2-year period. To make the data more consistent all extracts from a given vehicle test were assayed as a batch. Thus 12 individual extracts were assayed in parallel to remove as many biological variables as possible in making comparisons within each vehicle test.

In addition to the normal positive controls to verify the activity of the tester strain, a single bulk diesel particulate extract sample was used to verify the activity of the tester strain. Figures 6.1 and 6.2 show the project chronology of the 5 µg dose of 2-NF (2-nitrofluorene) and the 0.5 µg dose of NQNO (4-nitroquinoline-N-oxide). The average of 74 measurements for those two positive controls was 736±11% and 563±11%, respectively.

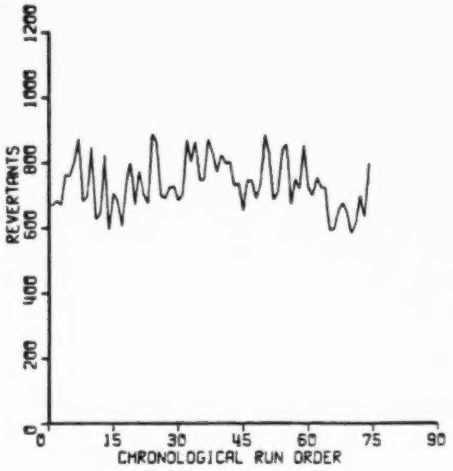


Figure 6.1 Chronology of Ames activity of 5 ug dose of 2-NF (2-nitrofluorene).

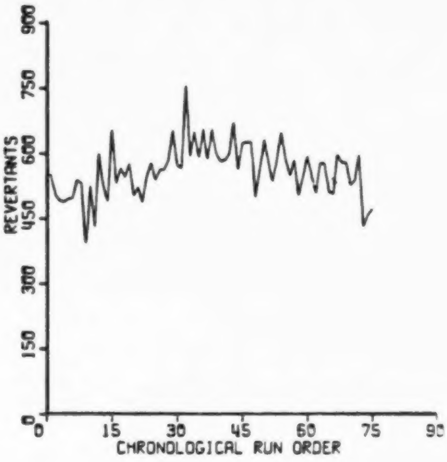


Figure 6.2 Chronology of Ames activity of 0.5 ug dose of NQNO (4-nitroquinoline-N-oxide).

The particulate extract control sample used throughout the assay originated from Car #5 as part of a particulate collection effort to produce a large extract sample for chemical analysis. Aliquots of this extract were kept in freezer storage and included in the assay of each batch of 12 extracts from a single vehicle test. Rather than use a single dose of this control extract in an assay wherein the real use of the data was slope determination, a 4 dose control extract protocol was adopted. Control extract doses of 25, 50, 75 and 100 µg were used as part of each batch of extracts and the slope of the control standard was computed. These results are presented in Figure 6.3 showing chronologically the 74 slope values computed from the single extract sample used throughout the project. The mean slope throughout the project was 2.13 revertants/µg extract with a coefficient of variation of 13% which compares favorably with the 11% found for the pure chemical controls.

The consistency of the diesel extract control activity throughout the project provides an interesting measure of sample degradation, a topic of considerable concern and experimental attention. In future examination of the project data the control extract slope value may be used to normalize project data to a constant control slope value, but this step was not possible in the preparation of the report.

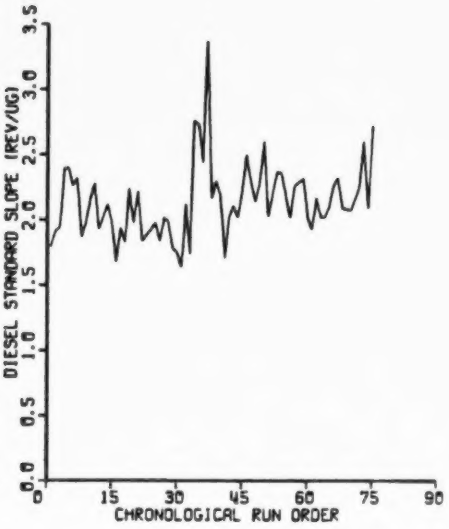


Figure 6.3 Chronology of Ames slope of diesel standard extract (25, 50, 75, 100 ug doses).

FACTORS AFFECTING ASSAY RESULTS

Filter and Extract Storage

The relative consistency of the TA98(-) response to the diesel extract control sample over the time period of the project was encouraging. The extract sample in this case was kept in freezer storage. Additional data were collected to examine storage effects on extract as filter bound particulate, dichloromethane (DCM) solution, and dried extract. These investigations used the 50 cm x 50 cm filters from the duplicate driving cycles of a given phase in the first 34 vehicle tests. During this portion of the project HFET and CFDS cycles were run in the afternoon and repeated after the FTP of the next day. The filters from these duplicate cycles were considered as identical, and this assumption was undoubtedly the limiting factor in interpreting the experiments described below. Some of these filters were extracted and assayed, some were kept as filters, and some were extracted with the extract kept in DCM solution, while others were kept as solvent-free extract. All samples were kept in freezer storage at -80°. Figures 6.4 and 6.5 show the number of days each filter was kept in any of the above storage conditions, and also give the specific TA98(-) activity.

In several cases it can be seen that the method of storage had little effect on the mutagenic activity, while in others a significant change would be projected. Given the uncertainty in what these "matched" filters would have given at time zero, it is impossible to quantify the changes in these samples. The relative similarity regardless of storage history does suggest that the direct acting mutagenic agents do persist in these samples over an extended period of time.

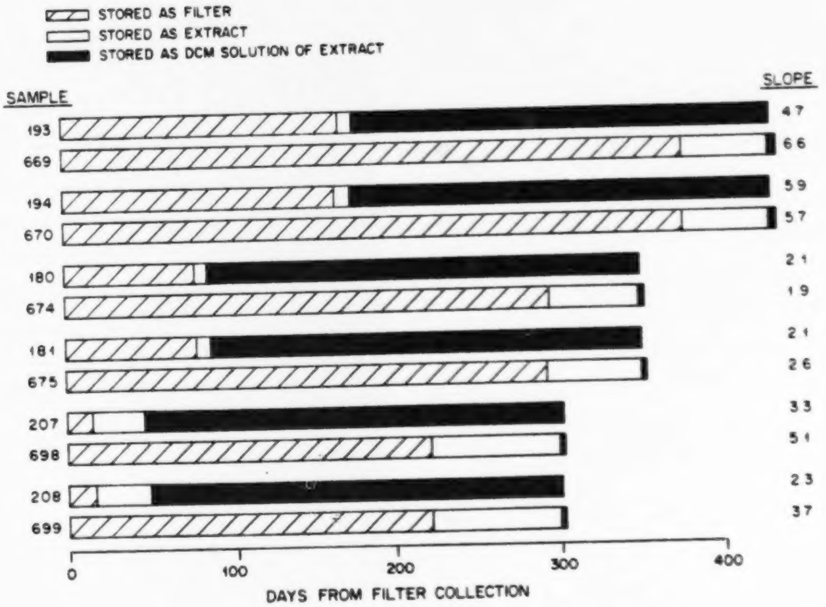


Figure 6.4 Effects of long-term sample storage on mutagenic response - storage as extract in DCM vs. storage as filter.

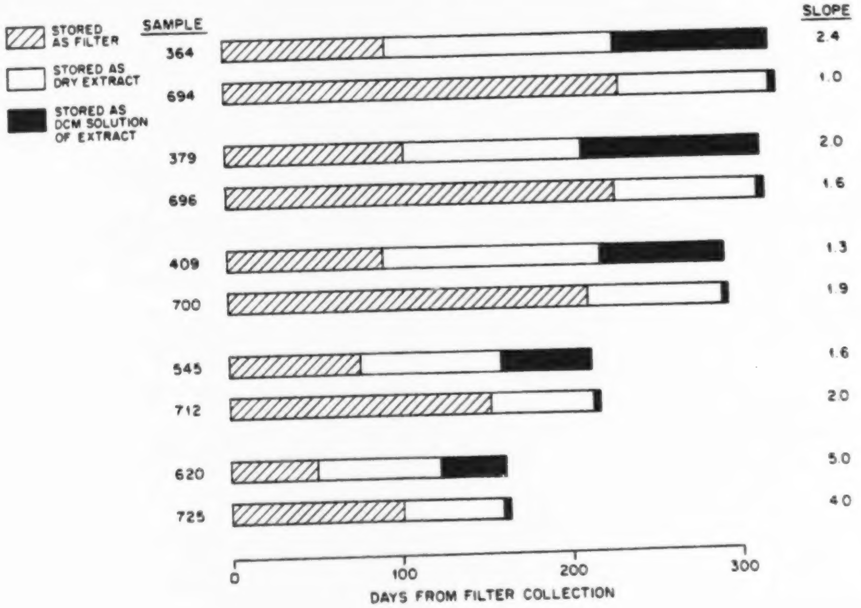


Figure 6.5 Effects of long-term sample storage on mutagenic response - storage as extract vs. storage as filter.

Effects of Incubation Period

The length of incubation time for the assay protocol was 72 hours for most of the work reported here. Figure 6.6 shows the results of an experiment to determine the effect of incubation time on the assay response. Revertant counts are shown for several chemical positive controls and the diesel particulate extract (DPE) control for incubation periods from 48-120 hours. The relative consistency of all the results indicates that the extract incubation time was not an important variable in the observed revertant counts, and that the 72-hour protocol value was acceptable.

Plate Count Reproducibility

The reproducibility of the assay protocol within a given day was measured by assaying 10 plates containing a constant 50 µg DPE dose. The results are shown in Figure 6.7, showing a 6% coefficent of variation within this particular test.

Effects of High Doses on Slope

The highest extract dose used in a linear regression will change the computed slope even at low doses where the R^2 values would indicate a satisfactory fit for both choices. Table 6.1 shows a random sample of 10 extract samples wherein different high doses of 30, 50, 100 and 200 µg were used to compute the slope. From the normalized results at the bottom of Table 6.1 a rough indication of how the high dose choice affects the slope can be seen. When the 30 µg dose is considered as the base, the 50, 100, and 200 µg high doses gave a 5%, 15%, and 42% reduction in slope respectively.

Activity Measurement from "Duplicate" Samples

As part of an experiment for another purpose, a number of 50 cm x 50 cm filters were collected from Cars #1 and #5 (Volkswagen and Oldsmobile loan cars) operated repeatedly on the 50C cycle. A sideline of the experiment gave individual extract samples for each filter. Unfortunately, the program did not include detailed extract emissions data (% extract or extract g/mi). The individual extract samples were assayed, and the slopes from each consecutive 50C are shown in chronological run order in Figure 6.8. The Oldsmobile data are very uniform whereas the Volkswagen data exhibit a marked increase throughout the test period. The magnitude of the slopes for the Volkswagen in the third and subsequent runs were significantly higher than for any other 50C values for the vehicle. No obvious vehicular reason can be given for these results.

These data suggest that at the current state of capability the Ames TA98(-) assay as a particulate characterization tool is subject to variability that impacts its interpretation. One cannot distinguish slopes that differ by only a few percent. Differences of 100% are likely to be indicative of real sample effects but could easily result from unknown parameters in the experiment from which the samples originate.

The overall uncertainty in quantitative Ames data is the combination of the uncertainties in the sampling and the lab analysis. It has become evident that control of test parameters as usually practiced may not always provide reproducible Ames data. Our knowledge of the test parameters affecting Ames data is very limited and therefore a large uncertainty exists in its quantification. We have therefore analyzed a large number of samples and grouped the data in the hope of reducing random error. Remedies to systematic errors such as artifact production, sample degredation and

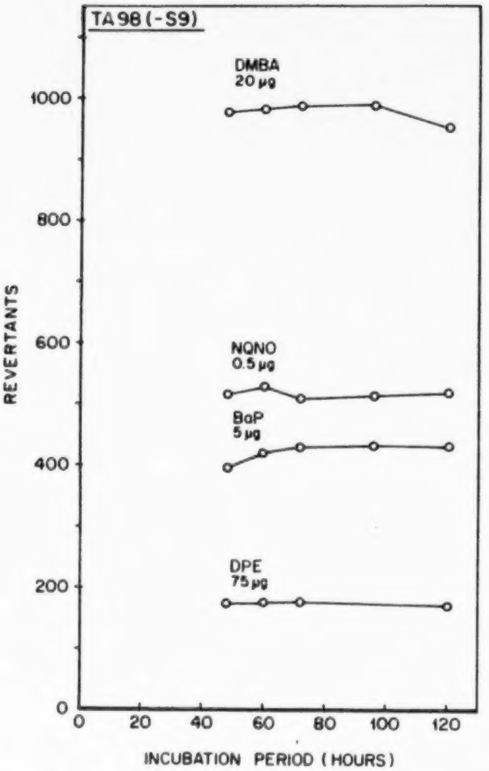


Figure 6.6 Effect of incubation period on mutagenic response.

TABLE 6.1

EFFECT OF HIGH DOSES ON SLOPE OF DOSE-RESPONSE CURVE

	SLOPE (Revertants/μg)			
	Highest Dose Used in Fit (μg)			
Sample	30	50	100	200
886	4.1	3.6	4.1	3.8
921	1.3	1.4	1.3	1.0
931	1.7	2.1	1.8	1.4
939	2.0	1.9	1.4	0.7*
965	2.3	1.8	1.5	1.8
987	2.1	1.9	1.4	1.0
1009	15.3	15.7	12.1	8.3
1033	4.2	4.1	4.5	3.7
1056	3.8	3.5	3.3	2.4
1068	3.2	2.3	2.5	2.2
Average	4.0	3.8	3.4	2.6
Normalized	1	0.95	0.85	0.58

*Not on linear portion of curve.

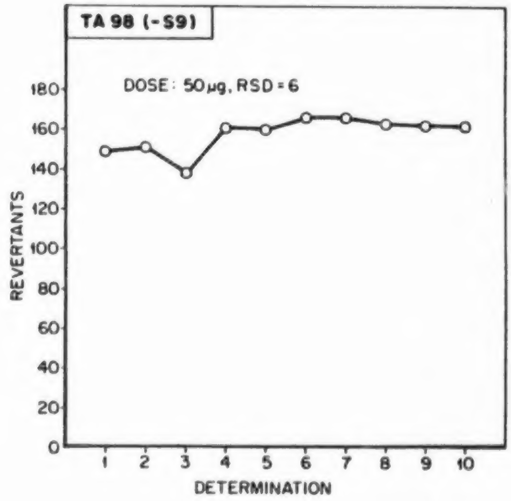


Figure 6.7 Reproducibility of mutagenic response for ten replicate plates of diesel standard extract.

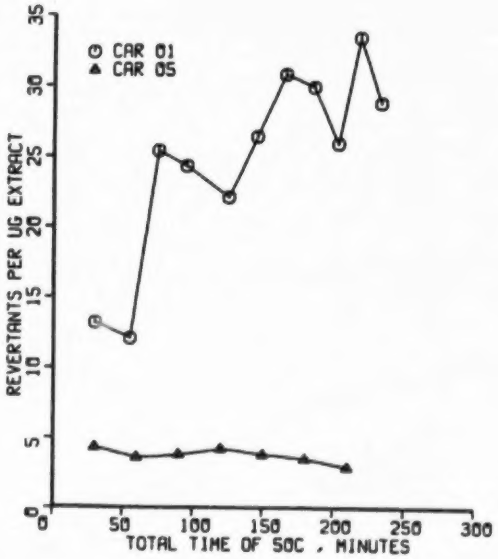


Figure 6.8 Reproducibility of mutagenic response for replicate 50C filter samples.

matrix interferences are generally beyond the scope of this work. The useful application of the Ames test to the assessment of the bio-hazard of diesel particulate extract has not been sufficiently refined to permit unequivocal interpretation of the quantitative data.

AMES TEST RESULTS

Fuel and Lubricating Oil Effects

Phase 1 and Phase 3 differ in the fuel and lubricating oil used. In Phase 1 the car is tested with fuel and oil which were in the vehicle when received, while in Phase 3 control fuel and oil are used. The combined effect of this fuel and oil change was investigated by comparison of TA98(-) activities of the two phases. For five driving cycles (IDLE excluded) the ratio of activity of Phase 1 to the activity of Phase 3 was calculated and called the "cycle-phase-ratio". The average of the five cycle-phase-ratios for a given test was designated the "test-phase-ratio". The average of all test-phase-ratios within a vehicle group was defined as the "group-phase-ratio". Table 6.2 gives the group phase ratios data and the coefficients of variation for bioactivity parameters.

TABLE 6.2. AMES ACTIVITY, GROUP-PHASE RATIOS

		GM	VW	MB	OTHER
# test-phase ratios		29	18	8	14
$\frac{\text{revertants}}{\mu\text{g extract}}$	Ratio	1.24	1.10	0.97	0.97
	CV,%	42	70	28	25
$\frac{\text{revertants}}{\mu\text{g particulate}}$	Ratio	1.13	1.26	1.09	1.04
	CV,%	39	74	31	35
$\frac{\text{revertants}}{\text{mile}}$	Ratio	1.16	1.29	1.10	1.04
	CV,%	38	69	29	38

The group-phase ratios in Table 6.2 are in the range of 0.97-1.29. The coefficients of variation are 30-40% for the General Motors and Mercedes-Benz groups, and approximately 70% for the Volkswagen group. Thus while no overall systematic phase effect could be statistically defined for these data sets, significant phase effects were observed on an individual test basis. When significant Ames activity phase differences were observed in a given test, the change was generally observed for all test cycles. This suggests that these phase changes were real and not spurious results of a single analysis. This leaves open the question of whether such phase changes are due to the fuel/lubricating oil changes between the phases or some other unknown change in the vehicle itself. These results comparing Ames activity group-phase ratios are in essential agreement with previously published results (ratios of 0.98 to 1.17) for a much smaller Ames data base (31).

Mileage Accumulation Effects

In order to examine mileage accumulation effects on Ames activity, the Phase 1 and Phase 3 test cycle data from a given vehicle test (IDLE assays not included) were averaged to obtain a single Ames activity parameter for each vehicle test. Figure 6.9 shows these data connected point-to-point for each car. While Ames activity does exhibit large fluctuations with accumulated miles, Figure 6.9 suggests that mileage accumulation is not the primary cause of the observed changes. This was supported by examination of the data for the high-mileage Car #11 (120,000-170,000 miles). This car exhibited Ames activity essentially similar to the average of other project cars. All mileage accumulation effects are difficult to assess due to the problems of obtaining consistent quantitative Ames activities over long time periods.

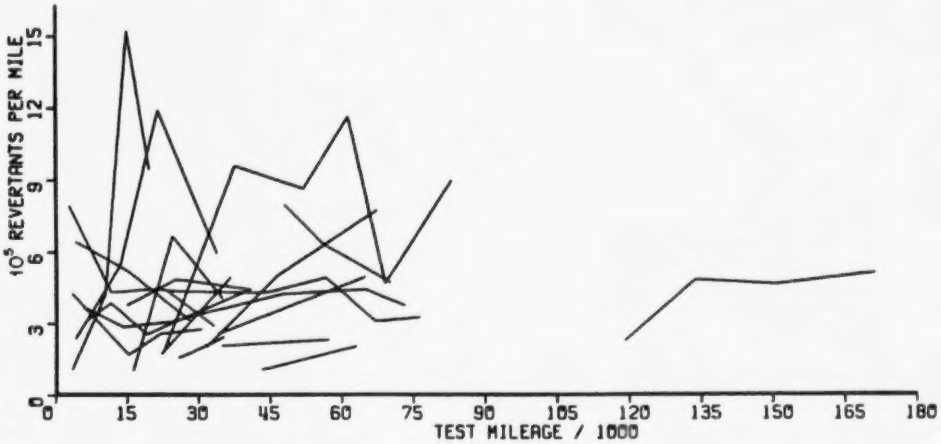


Figure 6.9 Mileage accumulation effects for averaged Ames activity.

Vehicle Group Averages

Figures 6.10a, b, c, d give the average values of Ames activity for each cycle by vehicle group. Four Ames activity characterization parameters are shown: specific activity of the extract (revertants/µg extract); activity expressed in terms of a common amount of emitted particulate (revertants/µg particulate); activity expressed per vehicle mile (revertants/mile); and fuel specific activity (revertants/kg fuel consumed).

Some effects of test cycle are evident in Figures 6.10a, b, c, d especially for the Volkswagen group and for the NYCC for all groups. The General Motors group exhibited essentially unchanged extract and particulate based activity over all test cycles.

The FTP and CFDS generally had the highest activity measure regardless of vehicle group, test cycle, or activity parameter. No explanation is offered to account for this result at present. Since the FTP is the only cycle with a vehicle cold-start included, it is qualitatively different than other test cycles, as opposed to quantitative variations in such parameters as speed, acceleration, idle time, etc. Early in the

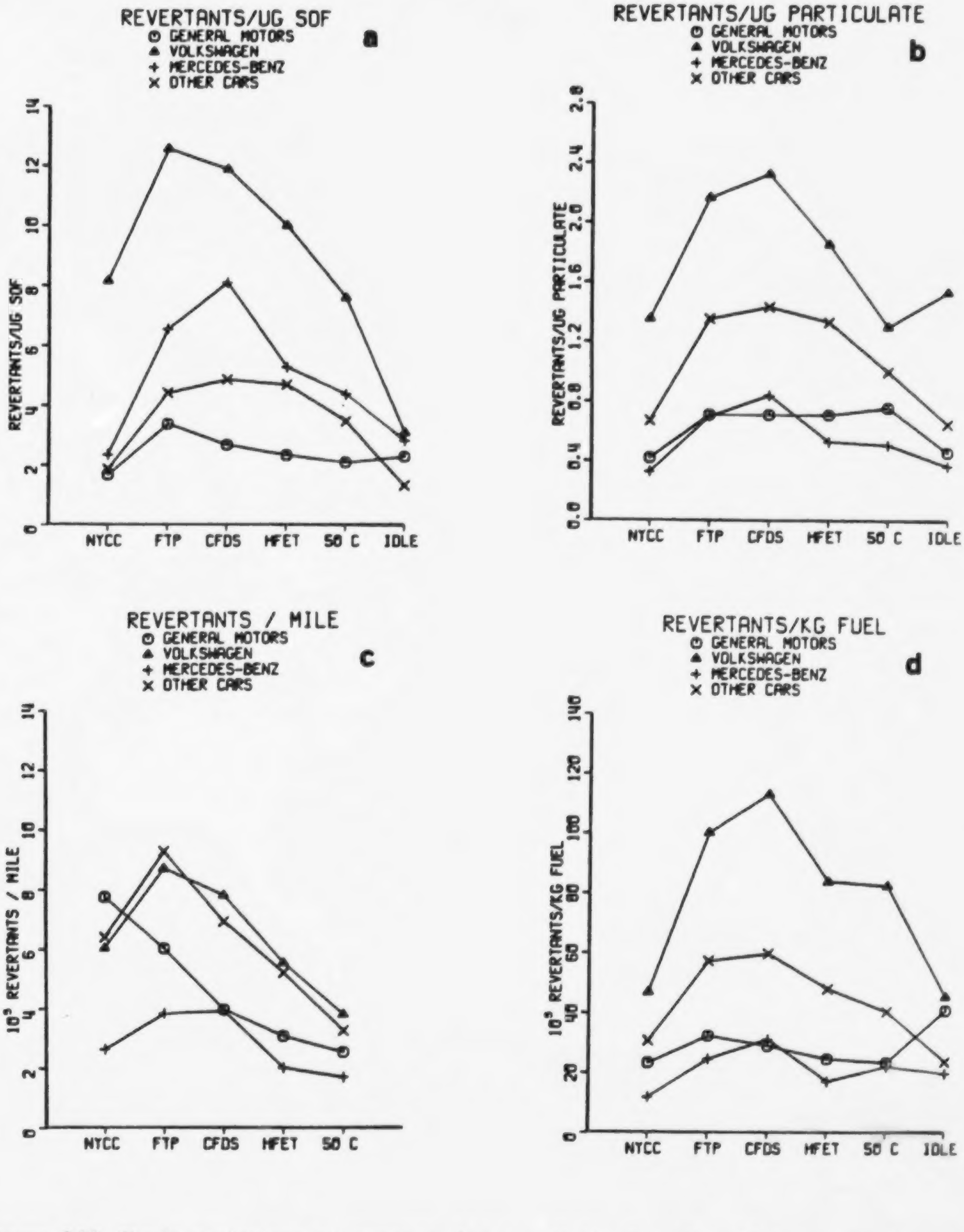


Figure 6.10 Cycle variations of average Ames activity for all vehicle groups in units of: (a) revertants/ µg extract, (b) revertants/ µg particulate, (c) revertants/mile, and (d) revertants/kg fuel.

project it was noticed that FTP Ames activities were frequently higher than for other cycles of the same day. A short series of special tests were conducted on Cars #1 and #5 to examine the effect of cold-start operation on particulate, extract, residue, and Ames activity in the winter of 1981. These tests revealed the Bag 1 (FTP cold-start) Ames activity (revertants/mi) to be 40-80% higher than the Bag 3 (FTP hot-start) values (37). While this finding may contribute to an explanation of the relative Ames activity results for the FTP, the Ames activity result for the CFDS will require a more fundamental understanding of the interaction of various test cycles and complex emission products.

The coefficients of variation associated with the group averages of Figure 6.10 are quite large, and range from a low of 30-50% for the Mercedes-Benz group, 50-70% for General Motors, to 70-100% for the Volkswagen group. While vehicle group and test cycle differences are apparent, there are major unexplained variations for groups and different activity parameters.

Bioactivity and Emissions Correlations

Linear correlation coefficients and the significance level of the coefficients were computed for bioactivity and extract-residue data. Bioactivity was expressed in five parameters: revertants/mile, revertants/kg-fuel, revertants/μg extract, revertants/μg residue, and revertants/μg particulate. Emission extract and residue parameters were: grams extract/mile, grams residue/mile, grams extract/kg fuel, grams residue/kg fuel, % extract, and the grams residue/grams extract ratio. Three threshold significance levels (SL) were selected: SL=1 at alpha=0.05, SL=2 at alpha=0.01, and SL=3 at alpha=0.005. The determination of the significance level was made by testing a population zero correlation null hypothesis ($H_0: \rho = 0$) against the population non-zero correlation alternative hypothesis ($H_a: \rho \neq 0$) using the test statistic z:

$$z = (\sqrt{n-3}\,/\,2) \ln \left[(1+r)\,/\,(1-r)\right]$$

where z is approximately normally distributed, n is the number of samples, and r is the sample correlation coefficient (32). From this test it was determined if the sample correlation coefficients were statistically significant and, if so, the degree of significance.

The data were stratified by driving cycle, test phase, and vehicle type to yield individual sample data sets. Data were also segregated simply by: driving cycle and test phase without regard to vehicle type; driving cycle and vehicle type without regard to test phase; and driving cycle without regard to either vehicle type or test phase. Five driving cycles were studied: FTP, CFDS, HFET, NYCC, and IDLE.

Correlation coefficients and signficance levels for the data segregated by driving cycle and vehicle type (but not by test phase) are presented in Appendix E. By lumping the test phases together, a greater number of statistically significant sample correlation coefficients were observed than for segregated phase data sets. The results showed the same general features, however, for both individual phase and the lumped phase data sets. The large quantities of data generated by the correlation exercise make it necessary to restrict this discussion to the more universal case of lumped phases.

It is recognized that linear correlation may not appropriately describe all parameter relationships, and this investigation, therefore, must be considered preliminary in nature rather than comprehensive. The results are suggestive of possible parameter associations which should receive additional statistical attention in the form of non-linear correlation and multiple parameter correlation studies.

Of primary consideration in this analysis was the determination of the degree and significance of the correlation between emission(extract and residue) parameters and the bioactivity parameters. The first item of importance, therefore, was to determine the sample correlation coefficients and levels of significance between the emission parameters themselves on grams/mile and fuel-specific (grams/kg fuel) bases, segregated by driving cycle and vehicle type. These results are given in Table 6.3. Approximately half of the observed correlation coefficients in Table 6.3 are not statistically significant and only 20% are significant at the alpha=0.005 level. Thus extract and residue do not, in general, exhibit strong linear correlation within the context of these data.

TABLE 6.3 EXTRACT/RESIDUE SAMPLE CORRELATION COEFFICIENTS BY DRIVING CYCLE AND VEHICLE GROUP OVER ALL TEST PHASES

		Extract (g/mile)* Residue (g/mile)*			Extract (g/kg-fuel) Residue (g/kg-fuel)		
Driving Cycle	Vehicle Group	n	r	SL	n	r	SL
FTP	GM	74	.011	0	72	-.040	0
	VW	47	.052	0	47	.060	0
	MB	21	-.448	1	20	-.179	0
	Other	35	-.238	0	34	-.368	1
	All	177	.218	3	173	-.223	3
HFET	GM	73	.089	0	73	.049	0
	VW	46	-.038	0	46	-.033	0
	MB	22	-.549	3	22	-.193	0
	Other	37	-.492	3	37	-.473	3
	All	178	-.062	0	178	-.214	3
CFDS	GM	73	.216	1	73	.113	0
	VW	48	.078	0	47	.073	0
	MB	22	-.648	3	22	-.295	0
	Other	36	-.581	3	36	-.502	3
	All	179	.164	1	178	-.141	1
NYCC	GM	29	-.019	0	29	-.140	0
	VW	16	-.602	2	16	-.676	3
	MB	9	-.252	0	9	.131	0
	Other	22	-.407	1	22	-.079	0
	All	76	.378	3	76	-.184	0
Idle	GM	72	.089	0	29	-.199	0
	VW	46	.223	0	17	.107	0
	MB	22	.068	0	10	.460	0
	Other	37	.260	0	22	.055	0
	All	177	.300	3	78	-.098	0

n = number of samples

r = sample correlation coefficient

SL = significance level where :

SL = 1 for $0.05 \geq \alpha > 0.01$

SL = 2 for $0.01 \geq \alpha > 0.005$

SL = 3 for $0.005 \geq \alpha$

* change units to g/minute for Idle driving cycle

In Table 6.3 it is observed that for all cars over the FTP cycle, extract and residue on a grams/mile basis show a very weak (r=.218) positive association but show a similarly weak (r= -.223) negative association on a fuel specific basis. This observation may be explained by the moderate negative correlations observed between fuel economy (miles per gallon) and both extract grams/mile (r= -.485; SL=3) and residue grams/mile (r= -.686; SL=3) for the FTP cycle.

A very weak but statistically significant negative correlation for extract and residue on a fuel specific basis (r= -.214; SL=3) was observed for all vehicles over the HFET cycle, and weak positive correlations were observed for all vehicles over the NYCC (r= .378; SL=3) and IDLE cycle (r= .300; SL=3) on grams/mile and grams/minute bases, respectively. Somewhat higher correlation coefficients were observed for specific vehicle groups; however, it is cautioned that the sample sizes for these data were small. Six data sets were observed to have correlation coefficients with absolute values greater than or equal to 0.549 which represents 30% or more explained variance as a result of a linear association.

It is not established here that extract and residue are independent parameters. It is observed, however, that for most of the vehicle groups and driving cycles, the linear correlation between extract and residue is either not statistically significant or, if significant, is not strong.

Table 6.4 lists the sign of the sample correlation coefficient and the significance level for each bioactivity-emission parameter pair by driving cycle and vehicle group. Sample correlation coefficients with absolute values of 0.60 or greater are indicated in Table 6.4 and listed specifically in Table 6.5. The general level of correlation between parameters in Table 6.4 is very weak. Typically significant r values range from 0.2 to 0.4. It is observed, however, that, in spite of the weak degree of correlation, independent data sets for driving cycles and vehicle types show considerable consistency for similar driving cycles in terms of the sign of the sample correlation coefficient for specific parameter pairs. For example, the revertants per μg extract parameter demonstrates such sign consistency for all vehicle groups over the FTP, HFET, and CFDS cycles when sample correlation coefficients with extract grams per mile, fuel specific extract, % extract, and the residue to extract ratio are considered.

For other parameters, effects are observed which are vehicle group specific. A consistency in the sign of the sample correlation coefficient is observed for the General Motors group over the higher speed cycles for the revertant per μg residue vs. residue gram per mile and fuel specific residue parameter pairs. Similarly, for the Volkswagen group over the higher speed cycles, a consistent, weak, positive sample correlation is observed for the revertant per mile, fuel specific revertants, and revertant per μg particulate vs. residue to extract ratio parameter pairs.

The lower speed cycles, NYCC and IDLE, frequently do not exhibit the same level of significance as the higher speed cycles for specific vehicle groups.

One of the most notable observations is that revertants per μg extract and the extract emission parameters are negatively correlated, albeit weakly, possibly indicating that as greater quantities of extractibles are emitted by a vehicle the proportion of bioactive organics diminishes. The bioactivity per μg extract sample correlation coefficients with fuel specific residue and the residue to extract ratio parameters are positive. Furthermore, the revertants per mile and fuel specific revertant parameters tend to show a more general pattern of statistical significance for correlation vs. residue gram per mile and fuel specific residue than vs. the extract parameters. The question posed by these observations is that of the interaction of extractible emission organics with inextractible carbonaceous and inorganic emission matter which together make up the total emission particulate matter, and the consequences of any such interaction with respect to the biological activity of the extractible organics. It may be postulated that since revertants per μg particulate and emission parameter sample correlation coefficients exhibit generally low levels of

TABLE 6.4 BIOACTIVITY/EMISSION PARAMETER SAMPLE CORRELATION COEFFICIENT SIGNS AND SIGNIFICANCE LEVELS BY DRIVING CYCLE AND VEHICLE GROUP OVER ALL TEST PHASES

		Revertants per mile ¶					Revertants per kg fuel					Revertants per µg extract					Revertants per µg residue					Revertants per µg particulate				
	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
Extract grams per mile¶	GM			+1		+3					+1	-3	-3	-3	-3	-1					+3	-3	-2	-1		+1
	VW					+3						-3	-3	-3							+1		-1			
	MB											(-3)	(-3)	-1												
	Other	+1				+3						-2	-3	-3	-1	-3	+3	+2	+2							-3
	All	+1			+1	+3		-1	-1			-3	-3	-3	-3	-3						-3	-3	-3	-1	
Residue grams per mile¶	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
	GM					+1					+1					+1	-3	-3	-3			-1	-2	-3		
	VW	+3	+3	+3	+1		+3	+3	+2	+1		+1	+1		+1											
	MB		+1	+3				+1	+2				+1	(+3)					+1	-1				+1		-1
	Other		+3	+3	+1	+3	+1	+3	+3	+1		+1	(+3)	(+3)	+2					-1			+1	+1		-1
	All		+1		+3	(+3)	-3					-3			-1	-3	-3	-3	-3	-3	-3	-3		-3	-3	-3
Extract grams per kg fuel	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
	GM					+3					+1	-3	-3	-3	-3	-2					+3	-3	-2	-2		
	VW											-2	-3	-3									-1			
	MB											(-3)	(-3)	-1												
	Other	+1			+1					+1		-3	-1	-2		-3	+3	+3	+2	+2						-1
	All	+1			+3	+1				+1	+1	-3	-3	-3	-3	-1	+1			+1			-1	-1		
Residue grams per kg fuel	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
	GM				+1	+1				+1	+2					(+3)	-2	-3	-3			-1	-2	-3		+1
	VW	+3	+3	+3			+3	+3	+3			+2	+1	+1	(+2)	-1					-1					-1
	MB		+1	+3				+1	+3					+3					+1					+1		
	Other		(+3)	(+3)	(+3)		+1	(+3)	(+3)	(+3)		+2	(+3)	(+3)	(+3)	+1					-1		+2	+1	+1	
	All	+1	+3	+3	+3	(+3)	+2	+3	+3			+3	+3	+3			-2			-3	-3		+3	+2		-1
% Extract	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
	GM					+3						-3	-3	-3	-3	-3		+1	+1		+3	-1				+1
	VW		-3	-1		+3		-3	-1		+1	-3	-3	-3	-1					+1	+3		-1	-1		
	MB											(-3)	(-3)	-1												
	Other		-2	-1		+3		-3	-2			-3	(-3)	(-3)	(-3)	(-3)	+1	+1	+2		+3					
	All		-1			-3		-3	-1			-3	-3	-3	-2	-3	+3	+3	+3	+3	+3		-1	-1		+3
Residue to Extract Ratio	Cycle**	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I	F	H	C	N	I
	GM					-3						+3	+3	+3	+3	+2		-3	-1		-3					-1
	VW	+1	+3	+1			+1	+3	+1			+3	+3	+3	(+3)							+1	+1	+1		
	MB											(+3)	(+3)	+2						(-1)	-1					
	Other		+2	+2				+3	+3			(+3)	(+3)	(+3)	+1	(+3)	-1		-1				+1	+1		
	All							+1			-1	+3	+3	+3	+1	+1	-1	-1	-1	-3	-3					-3

* Numbers in table refer to the significance level (α level) of the sample correlation coefficient for the given parameter pair and the vehicle group and driving cycle indicated. The sign preceding the significance level is the sign of the sample correlation coefficient. The significance levels and corresponding α levels are :

SL=1 for 0.05 ≥ α > 0.01 ; SL=2 for 0.01 ≥ α > 0.005 ; SL=3 for 0.005 ≥ α

** Driving cycle code : F=FTP, H=HFET, C=CFDS, N=NYCC, I=Idle

¶ For Idle cycle change units to per minute basis.

Circled values (eg. (+3)) indicate that the absolute value of the sample correlation coefficient was greater than 0.600. Uncircled values indicate sample correlation coefficients which, although statistically significant (i.e. non-zero), had absolute values less than 0.600. Correlations were frequently very weak (|r|< 0.3) and complete listings of values may be found in the Appendices.

TABLE 6.5 BIOACTIVITY/EMISSION PARAMETER PAIRS WITH SAMPLE CORRELATION COEFFICIENT ABSOLUTE VALUES IN EXCESS OF 0.60

Bioactivity Parameter	Emission Parameter	Driving Cycle - Vehicle Group	n	r
Revertants per mile	Residue g/mile	NYCC - All	165	.661
	Residue g/kg-fuel	HFET - Other	33	.609
		CFDS - Other	32	.622
		NYCC - Other	18	.638
		Idle - All	67	.660
Revertants per kg fuel	Residue g/kg-fuel	HFET - Other	33	.654
		CFDS - Other	32	.664
		NYCC - Other	18	.631
Revertants per µg extract	Extract g/mile	FTP - MB	19	-.655
		HFET - MB	20	-.617
	Residue g/mile	HFET - Other	33	.631
		CFDS - Other	32	.629
		CFDS - MB	20	.682
	Extract g/kg-fuel	FTP - MB	18	-.647
		HFET - MB	20	-.636
	Residue g/kg-fuel	HFET - Other	33	.714
		CFDS - Other	32	.693
		NYCC - Other	18	.689
		NYCC - VW	14	.612(SL=2)
		Idle - GM	26	.639
	% Extract	FTP - MB	19	-.648
		HFET - MB	20	-.659
		HFET - Other	33	-.654
		CFDS - Other	33	-.605
		NYCC - Other	18	-.605
		Idle - Other	33	-.623
	Residue to Extract Ratio	FTP - MB	19	.719
		HFET - MB	20	.627
		FTP - Other	32	.605
		HFET - Other	33	.707
		CFDS - Other	32	.731
		Idle - Other	33	.646
		NYCC - VW	14	.685
Revertants per µg residue	Residue to Extract Ratio	NYCC - MB	7	-.721(SL=1)

Significance Level (SL) is 3
($\alpha \leq 0.005$) unless otherwise indicated

statistical significance, there may be an interaction of extract and residue parameters which determines bioactivity rather than one or the other independently determining the bioactivity. This hypothesis is by no means proven in these data; the question is merely raised for future research consideration.

In certain cases a sample correlation was noted within specific vehicle groups, but the sign of the correlation changed for the "All" group (unsegregated data for all cars without regard to vehicle type). This is most pronounced for the revertants per minute and % extract parameters for IDLE. Explanation is made by considering two factors: first, the correlations are very weak, and, second, the pairwise data points may fall into approximately discrete regions. Thus within a vehicle type, the limited data could exhibit a weak positive association but the location of grouped data regions could show an overall weak negative association as observed by the "All" group.

Finally, Table 6.5 presents the strongest (in a relative sense) sample correlation coefficients observed for the bioactivity-emission parameter pairs. The absolute values of the correlation coefficients in Table 6.5 lie in the 0.60 to 0.73 range.

Two points are noted from Table 6.5; the "Other" vehicle group is more frequently observed with relatively high sample correlation than are the specific vehicle groups, and, while % extract and residue to extract ratio are inverse expressions for the same physical parameter, the mathematical formulation of the ratio leads to a statistically significant increase in the absolute value of the sample correlation coefficient for the HFET and CFDS "Other" data and a marginally significant increase for the FTP Mercedes-Benz data. One explanation for the higher sample correlation observed for the "Other" group is that data points for Car #15, an Audi, tended to be variable but generally higher in both emission and bioactivity parameter values than data for other cars in this group. The higher correlation is thus chiefly due to the effect of this vehicle.

Additional work with these data using non-linear correlation and multiple parameter correlation techniques is suggested.

Correlations of Ames Activity with Extract/Residue

Included in the project data base are many parameters which could correlate with Ames activity changes. Many pair-wise correlation coefficients were calculated but none was found to adequately explain the observed changes in Ames activity. Earlier researchers have found that fuel system parameters strongly affect Ames results. An EPA study (38) showed that injector malfunction can dramatically alter Ames activity. Work conducted at Nissan Motor Co. Ltd. (39, 40) showed that injection system configuration had significant activity effects.

In the study the Ames activity frequently correlated with residue as well as, or better than, with extract or particulate. The extract has received the majority of recent attention due to the Ames activity universally found in extract samples. Chemical research into the extract has clearly documented that whatever chemicals are responsible for this activity, they constitute only a minute fraction of the extract, with the majority of the extract acting only as a diluent. There is no a priori reason why this small amount of active material might be considered to be related only to the extract. The active material may well have been originally associated with the residue, for instance, and this small quantity of material leached into the extract by the extraction process.

We have reported previously (37) the observation that one project vehicle, Car #2, exhibited inverse trends of extract (% extract) and specific Ames activity (revertants/μg extract) over 50,000 accumulated miles. Clark et. al. (41) reported that when large variations in extract were observed, the extract was inversely related to the mutagenic potency. Examination of all project cars for this characteristic showed most vehicles exhibited similar trends. Figures 6.11a, b, c, d show mileage accumulation trends of the extract and Ames activity for Cars #2, #4, #9 and #15 respectively. In each case the inverse relationship of the extract expressed as a percent of particulate to the specific activity of the extract is evident. Reversals in the extract trend with accumulated miles for unknown vehicle operational reasons do occur, and are mirrored by the Ames activity data.

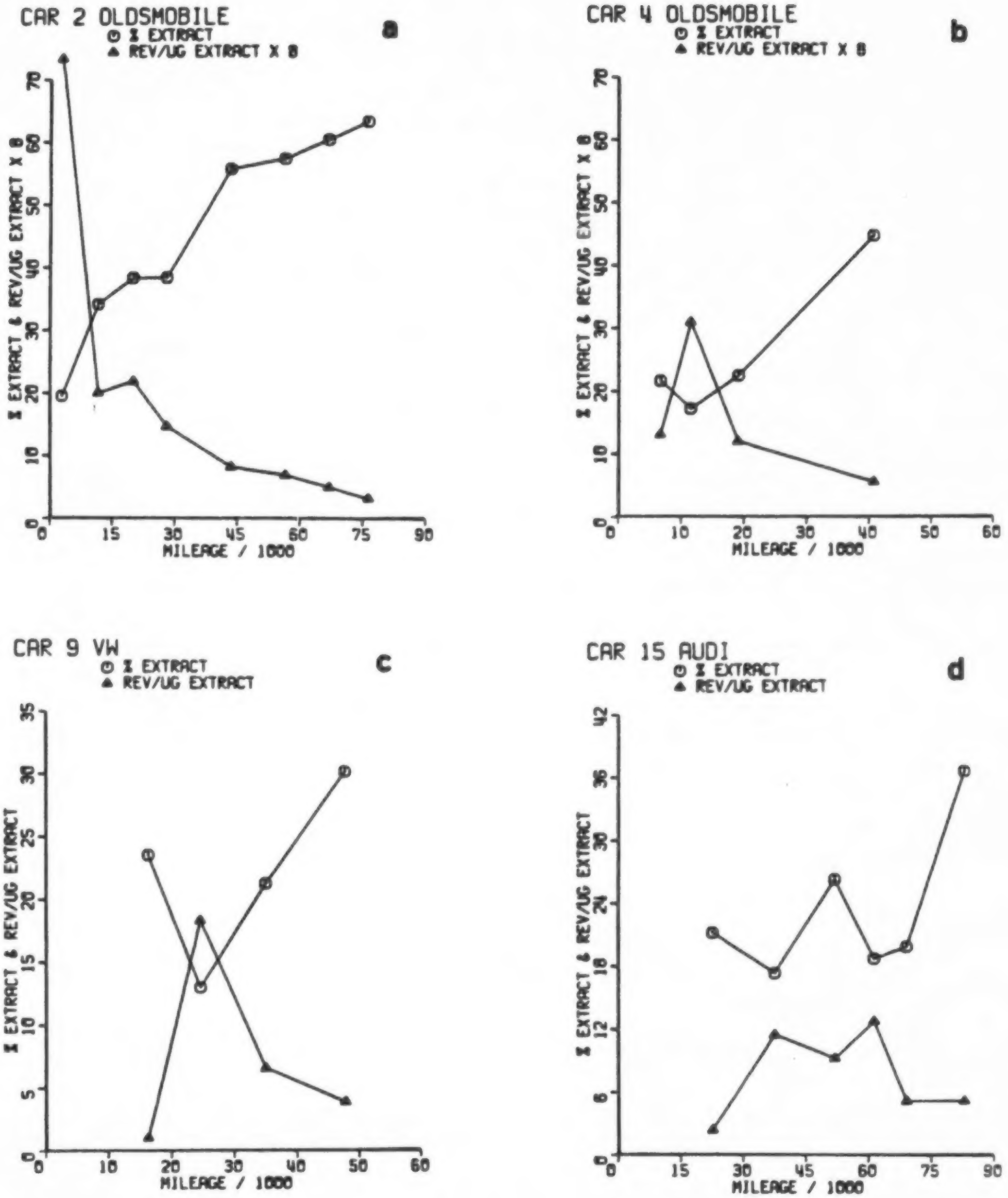


Figure 6.11 Mileage accumulation effects for extract and Ames activity, revertants/ µg extract for (a) Car #2, (b) Car #4, (c) Car #9, and (d) Car #15.

Figures 6.12, 6.13 and 6.14 show the vehicle group-average data for residue, extract, and revertants (per mile basis), each normalized to its FTP value, and plotted by test cycle. In Figure 6.12 the Ames activity and residue for the General Motors group are seen to have almost identical changes between cycles, except the NYCC. The similarity between these normalized residue/Ames activity data, as compared to the extract data, suggests the possibility that residue and not extract (at least extract by itself) be considered a probable original source of the Ames active material that ends up in the extract due to the extraction process.

Examination of Figures 6.13 and 6.14 does not show the same residue/revertant trend for the Volkswagen and Mercedes-Benz groups. However, in these groups the residue, extract and revertant data are all in general proximity, suggesting either could provide a basis for correlation.

The comparatively low values of the NYCC Ames activity values for all three groups in Figures 6.13 to 6.14 are unexplained. While both residue and extract are at their maxima for the NYCC, the Ames activity for the NYCC is distinctly lower, especially for the Volkswagen and Mercedes-Benz groups. This may be due to the large amount of time spent at idle, changes in particulate character due to the low average speed, stop-start driving, or other unknown factors.

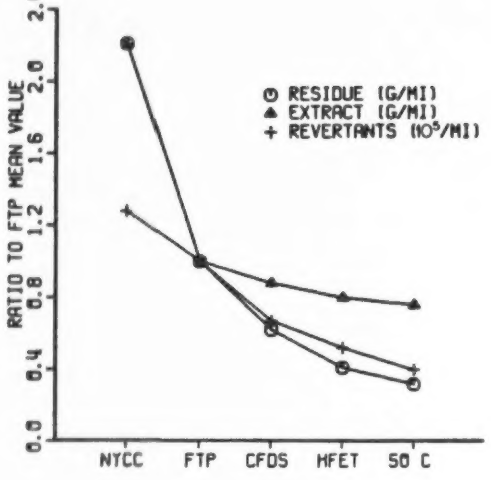


Figure 6.12 Cycle variation of residue, extract and revertants/mile normalized to the FTP for the General Motors group.

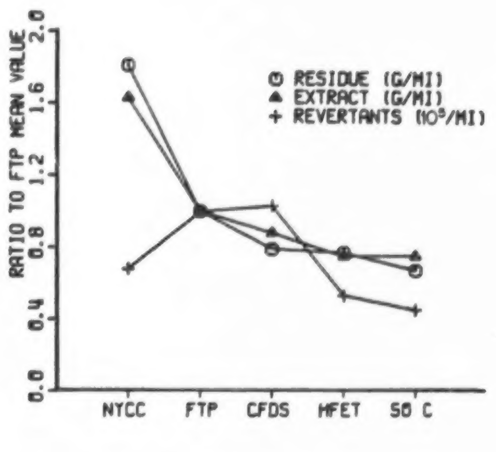


Figure 6.13 Cycle variations of residue, extract and revertants/mile normalized to the FTP for the Volkswagen group.

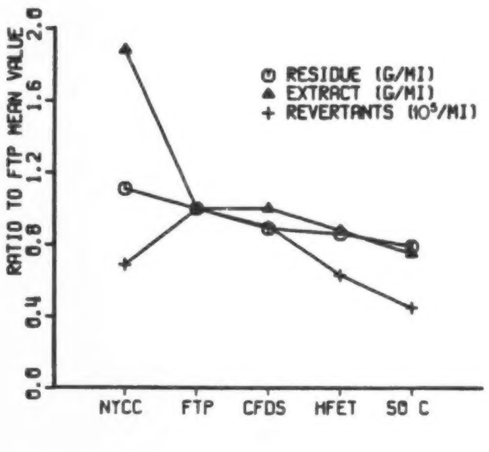


Figure 6.14 Cycle variations of residue, extract and revertants/mile normalized to the FTP for the Mercedes-Benz group.

SECTION 7

SPECIAL TESTS

INTRODUCTION

This section discusses several ad hoc experiments conducted during this project to investigate special situations related to interpreting project data. While the results presented here may impact the emission results and their interpretation, they are discussed separately within this section. The topics discussed include the effects of driving cycle sequence on emission results, characterization of particulate adhered to dilution tunnel walls, the exposure of particulate and extract to filtered exhaust gas, and effects of cold-ambient vehicle soak on emissions.

EFFECTS OF DRIVING CYCLE ORDER

The use history of a vehicle "immediately" prior to emission testing can have an effect on test results. The Federal Test Procedure therefore requires that certain procedures be followed in the half-day period before actual emission testing. In this study vehicles have been operated in a variety of test cycles after completing the three-bag FTP cycle. After completing 34 in-use vehicle tests the schedule of driving cycles was altered. Concern was raised that data collected before and after this "schedule change" would not be comparable because the vehicle's driving history immediately prior to a particular cycle would be different. Therefore an experiment was designed to determine if the order in which cycles were driven affected measured emissions. These experimental data can also be used to make emissions data reproducibility estimates.

Experimental Design

The "schedule change" test was conducted with a 1979 Oldsmobile (Car #5) with dynamometer conditions of 12.5 hp at 50 mph and 4000 lb I.W. and control fuel and lube (Phase 3 conditions). The test ran for seven days and was preceded by a complete normal vehicle test, and followed by an additional short special test. Thus data for more than a two week period of vehicle testing were available. Table 7.1 shows the days of testing and the order in which cycles were driven. Five FTP cycles were run over a seven day period employing five different "pre-conditioning" schedules. Three of these "pre-conditioning" schedules consisted of the same driving cycles driven in different sequences. On three consecutive days an FTP Bag 3 (only) was run after the vehicle was operated for about two hours on a repeated cycle. Particulate was collected from all cycles; gases were analyzed for all FTP bags and many other cycles.

TABLE 7.1 - SEQUENCE OF DRIVING CYCLES FOR SCHEDULE CHANGE EXPERIMENT

	July						August							
29	30	31	1	2	3	4	5	6	7	8	9	10	11	12
	FTP					FTP	FTP	FTP	FTP			FTP	(50C-30)	
	BAG 1					BAG 1	BAG 1	BAG 1	BAG 1			BAG 1		(50C)
	BAG 2					BAG 2	BAG 2	BAG 2	BAG 2			BAG 2	50C	50C
	BAG 3					BAG 3	BAG 3	BAG 3	BAG 3			BAG 3	50C	50C
	CFDS					50C	IDLE	HFET	50C				50C	50C
	HFET					50C	IDLE	HFET	IDLE				50C-30	50C
	NYCC					50C	IDLE	HFET	HFET					
	50C**					50C	IDLE	HFET						
	IDLE					50C	IDLE	HFET						
						50C	IDLE	HFET		SOAK	SOAK			
								HFET						
(50C)*					(50C)	50C	IDLE	HFET	(50C)			(50C)	50C-30	
HFET					HFET	SOAK	SOAK	SOAK	HFET			50C-5	50C	
HFET					HFET	FTP BAG 3	FTP BAG 3	FTP BAG 3	HFET			50C-5	50C-30	
HFET					HFET	IDLE	HFET	50C	HFET			50C-10	50C-30	
						HFET	50C	IDLE				50C-5		
SOAK				SOAK		SOAK	SOAK	SOAK	SOAK			50C		

* ( )For Equilibration only-no data taken.

** 50C is for 15 minutes unless a different time is specified.

Particulate Emissions

Preconditioning Effects--

Results for the FTP are shown in Table 7.2. The results for the July 30 to August 10 period show excellent reproducibility of the FTP despite variations in the preconditioning procedure, indicating a relative insensitivity to preconditioning. Bag 1 showed the lowest reproducibility, as would be expected for a cold-start cycle conducted after varied preconditioning. Bag 1 particulate values were highest following an IDLE (August 7) and lowest following a 50C (August 6).

TABLE 7.2 - DAY-TO-DAY VARIATIONS OF FTP PARTICULATE EMISSIONS

	July		August							
	30	3	4	5	6	7	10	Mean	σ	CV,%
BAG 1	1.044		1.061	1.037	0.969	1.193	1.074	1.063	0.073	6.9
BAG 2	0.863		0.882	0.875	0.890	0.824	0.850	0.864	0.024	2.8
BAG 3	0.823		0.786	0.827	0.789	0.755	0.791	0.795	0.027	3.4
FTP	0.890		0.893	0.896	0.879	0.882	0.881	0.887	0.007	0.8
BAG 3 ALONE -			0.722	1.834	0.696			0.709		

For cycles other than the FTP, the effect of preconditioning variation did not follow the FTP results. Table 7.3 shows these data for the HFET, 50C and IDLE. A very wide variation for the HFET is clearly evident, with the values for August 4, 5, and 7 (first run) being distinctly higher than other values. Table 7.1 shows that these cycles were driven either immediately after an IDLE or shortly after a long period of IDLE's. Note also in Table 7.2 that the FTP Bag 3 driven after an IDLE and 10 minute hot soak gave very high results. It is therefore evident that periods of idling substantially increase particulate observed in subsequent driven cycles. This may be caused by deposition of particulate in the exhaust system, by a change in the fuel system or some other unknown factor. The August 7 data are interesting in that the HFET driven immediately after the IDLE was very high but the HFET driven in the afternoon (following 15 minutes of 50C) was normal. Project test schedules always performed the IDLE as the last cycle of a phase, and the first cycle of the next phase was always preceded by 15 minutes of 50C before taking data. Therefore, these results were probably unaffected by this IDLE-effect phenomenon.

TABLE 7.3 - PARTICUIATE EMISSIONS FROM HFET, 50C AND IDLE - DAY-TO-DAY AND REPETITION VARIATION

	July			August						
Day	29	29	30	3	4	5	6	6	7	7
Filter	A	B	A	A	A	A	A	B	A	B
HFET-1	0.419		0.426	0.392	0.514	0.500	0.458	0.464	0.525	0.551
HFET-2		0.394		0.393			0.422		0.428	
HFET-3	0.393						0.431			0.389
HFET-4							0.425	0.458	0.380	
HFET-5							0.427			
HFET-6							0.430			
HFET-7							0.415	0.416		
HFET-8							0.451			

	July	August								
Day	30	4	4	5	6	7	10	11	11	12
Filter	A	A	B	A	A	A	A	A	B	A
50C-1	0.346	0.355	0.355	0.355	0.348	0.362	0.360	0.358		0.337
50C-2		0.341						0.369		0.335
50C-3		0.345	0.327					0.352	0.364	0.333
50C-4		0.327						0.365		0.333
50C-5		0.329						0.347		
50C-6		0.326	0.330					0.363	0.371	
50C-7		0.355						0.352		
50C-8								0.354		

	July	August				
Day	30	4	5	5	6	7
Filter	A	A	A	B	A	A
IDLE-1	0.175	0.175	0.171	0.172	0.180	0.179
IDLE-2			0.173			
IDLE-3			0.174	0.174		
IDLE-4			0.173			
IDLE-5			0.174			
IDLE-6				0.171		
IDLE-7			0.188			

Cycle Repetition Effects--

The effects of cycle repetition were studied by repeating a given cycle six or seven times over a period of about 2 hours. The only interruption between cycles was the time necessary to change filters. The cycles tested were the HFET, 50C and IDLE. Other cycles were not included because of the burden on drivers and vehicles. The data appear as part of Table 7.3 and are shown graphically in Figures 7.1 and 7.2.

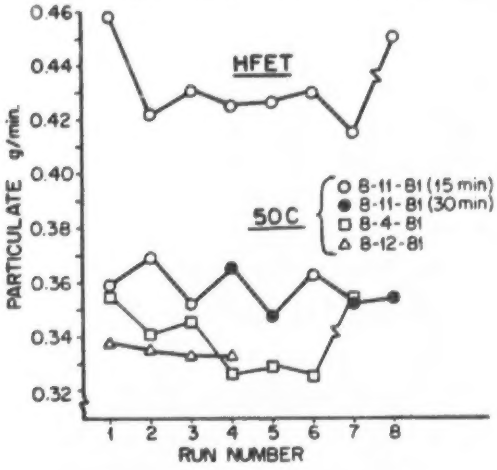


Figure 7.1 Variation of HFET and 50C particulate emissions for consecutive runs.

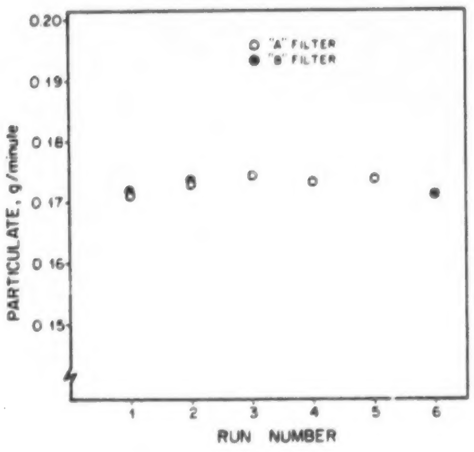


Figure 7.2 Variation of IDLE particulate emissions for consecutive runs.

The HFET shows a large decrease in particulate after the first cycle followed by a leveling off. Tests conducted after a lunch break yielded particulate levels similar to the initial value. The initial and final values in Figure 7.1 are thought to be greater than normal, possibly caused by the vehicle not being fully warmed up. For the first HFET, the preceeding FTP run of about 11 miles did not fully warm up the vehicle. For the final HFET, the soak period during lunch cooled off the vehicle. A similar trend appeared for the 50C as shown in the lower curves of Figure 7.1. The data given in Table 7.4 allow an assessment of the reproducibility of particulate measurements taken at different times:

Table 7.4 - Reproducibility of 50C Particulate, g/mi

Data From	Average ±1 σ	CV,%
August 4*	0.337±0.012	3.5
August 11	0.358±0.008	2.1
August 12	0.334±0.002	0.6
All Dates	0.347±0.014	3.9

*Excluding "cool-start" (after lunch) values.

The ratio of the August 11 average to the August 4 average is 1.062 and the comparable ratio for the August 12 average is 0.991. The 18 measurements have a range of 0.326 to 0.369 g/mi (average ±6%).

Idle particulate emissions are shown in Figure 7.2. The entire range of values for both filter probes is less than 0.003 g/minute. The absence of a driver for the IDLE most likely accounts for this high reproducibility. IDLE particulate measured on four other days had a range of 0.1750 to 0.1802 g/minute.

Gaseous Emission

FTP hydrocarbon, carbon monoxide and nitrogen oxide emissions are given in Table 7.5 and are shown graphically in Figure 7.3. Gaseous measurements were very reproducible with coefficients of variation increasing in the order: $NO_x < CO < HC$. This is probably indicative both of the consistency of the actual emission and of the experimental errors of analysis. Bag 1 HC and CO appear to change in unison. The July 30th HC and CO values are uniformly higher than the range of values for subsequent days.

Table 7.6 shows day-to-day variations in gaseous emissions for the HFET, 50C and IDLE. The HFET and 50C have emission variations (CV) which are comparable to those of the FTP (Table 7.5) except for nitrogen oxides which shows less reproducibility. The IDLE by contrast has much larger CV's for both hydrocarbons and carbon monoxide. This is attributed to the lower values of HC and CO observed during the August 5th test repetitions. A similar decrease appeared for the multiple runs of August 6th for the HFET and August 4th for the 50C. Although there are insufficient data to determine if this decrease is a real phenomenon, the data suggest that long periods of operation reduce gaseous emissions.

TABLE 7.5 - DAY-TO-DAY VARIATIONS OF FTP GASEOUS EMISSIONS

		July		August								
		30	31	3	4	5	6	7	10	Mean	σ	CV,%
HC g/mi	BAG 1	0.89			0.81	0.88	0.82	0.83	0.79	0.84	0.04	4.8
	BAG 2	0.61			0.54	0.53	0.59	0.54	0.52	0.56	0.04	6.5
	BAG 3	0.50			0.44	0.45	0.45	0.44	0.45	0.46	0.02	5.0
	FTP	0.64			0.57	0.58	0.60	0.57	0.55	0.58	0.03	5.4
CO g/mi	BAG 1	1.84			1.73	1.82	1.77	1.82	1.74	1.79	0.05	2.6
	BAG 2	1.80			1.70	1.76	-	1.74	1.71	1.74	0.04	2.3
	BAG 3	1.46			1.36	1.39	1.37	1.36	1.37	1.38	0.04	2.8
	FTP	1.71			1.61	1.67	-	1.65	1.62	1.65	0.04	2.4
NO_x g/mi	BAG 1	1.65			1.68	1.70	1.69	1.64	1.70	1.68	0.03	1.5
	BAG 2	1.94			2.00	1.95	-	1.93	1.97	1.96	0.03	1.4
	BAG 3	1.68			1.69	1.66	1.69	1.65	1.70	1.68	0.02	1.2
	FTP	1.81			1.85	1.82	-	1.80	1.84	1.82	0.02	1.1

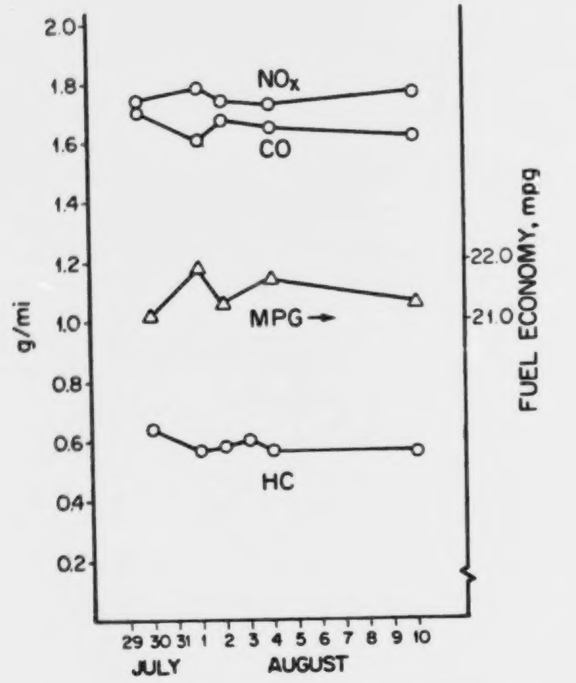


Figure 7.3 Variation of FTP gaseous emissions and fuel economy on successive days.

Fuel Economy

Fuel economy data are shown in Table 7.7. Two features of this data are readily noticeable: (a) the fuel economy changes very little from day-to-day and (b) fuel economy increases for consecutive repetitions of the same cycle. The data in Table 7.7 show relatively minor changes in fuel economy from day to day with coefficients of variation in the range 0.9 to 2.1%. On days when a cycle was repeated, however, the fuel economy increased at a rate of about 5-6% per hour for the HFET and 50C and 3% per hour for the IDLE. Since fuel economy was determined by the carbon balance method, this increase was due mainly to decreased CO_2 emissions as the HC and CO emissions changed very little. This may indicate that several hours of driving are required before maximum fuel economy is achieved. Therefore cycles driven at the end of a sequence may have better fuel economy than they would otherwise.

DILUTION TUNNEL

The use of a dilution tunnel for diesel particulate sampling may have unforeseen and non-predictible consequences. During the diesel testing program, it became necessary to test a catalyst (non-project) vehicle with the 50 cm x 50 cm filter in operation. The filter was found to collect an even light gray coating of particulate plus large aggregates of dark particulate which were obviously of diesel origin,

TABLE 7.6 - DAY-TO-DAY VARIATIONS OF HFET, 50C AND IDLE GASEOUS EMISSIONS

		July 30	3	4	5	August 6	6	6	7	Mean	σ	CV,%
	HC	0.30		0.32	0.31	0.30	0.29	0.28	0.32	0.30	0.02	4.9
HFET	CO	0.94		0.92	0.95	0.96	0.94	0.92	0.96	0.94	0.02	1.8
g/mi	NO_x	1.33		1.38	1.39	1.37	1.35	1.28	1.36	1.35	0.04	2.8
		30	4	4	4	5	6	7				
	HC	0.28	0.27	0.26	0.26	0.26	0.27	0.28		0.27	0.01	3.4
50C	CO	0.93	0.87	0.83	0.87	0.89	0.94	0.93		0.89	0.04	4.6
g/mi	NO_x	1.38	1.35	1.33	1.28	1.39	1.37	1.39		1.36	0.04	3.0
		30	4	5	5	5	6	7				
	HC	0.18	0.17	0.15	0.11	0.11	0.18	0.17		0.15	0.03	20.2
IDLE	CO	0.41	0.43	0.42	0.36	0.35	0.47	0.43		0.41	0.04	10.2
g/min	NO_x	0.18	0.18	0.17	0.17	0.17	0.17	0.17		0.17	0.00	2.8

TABLE 7.7 - FUEL ECONOMY VARIATIONS FOR DUPLICATE TEST, MPG[1]

	July 30	4	5	August 6	7	10	Mean	σ	CV,%
BAG 1	19.9	20.3	20.0	20.1	19.6	19.7	19.93	0.26	1.30
BAG 2	20.3	21.2	20.5	-	21.2	20.5	20.74	0.43	2.06
BAG 3	22.9	23.6	23.2	23.4	23.5	23.4	23.33	0.25	1.07
FTP	20.9	21.6	21.1	-	21.4	21.1	21.11	0.28	1.31
BAG 3 ALONE -	-	23.9	23.2	23.3	-	-	23.47	0.38	1.61
50C	33.1	33.5	33.6	33.6	33.0		33.36	0.29	0.86
50C		34.9							
50C		36.0							
HFET	31.8		31.2	31.1	31.5		31.40	0.32	1.01
HFET				32.0					
HFET				33.4					
IDLE[1]	166.0	173.6	170.7	172.1	170.0		170.48	2.86	1.68
IDLE			175.3						
IDLE			178.0						

[1] IDLE fuel economy in units of minutes idle per gallon.

indicating the potential for re-entrainment of particulate adhered to tunnel surfaces. Disassembly of the tunnel and probes showed all surfaces to be completely covered with a velvet black deposit of particulate approximately 1/16 in thick. Samples were collected from three tunnel locations and the tunnel was then thoroughly cleaned. A sample from the bottom of the tunnel midsection was analyzed for Ames activity and the results are shown in Table 7.8 identified as sample #1.

TABLE 7.8 - AMES ACTIVITY OF DILUTION TUNNEL PARTICULATE

Sample	Strain	S9	rev/µg ext	% ext	rev/µg part
1	TA98	+	21	10.8	2
1	TA100	-	50	10.8	5
1	TA100	+	22	10.8	2
4	TA98	-	17	20.0	3
5	TA98	-	25	16.0	4
6	TA98	-	27*	25.3	7*
10	TA98	-	24	12.1	3
11	TA98	-	200**	2.7	6**

*Slope difficult to determine - approximate value.
**All doses gave responses of 2100 rev/plate or greater.

About nine months later the tunnel was again disassembled and eight samples were collected at various points in the tunnel and probes as identified in Figure 7.4. Portions of five of these samples were extracted with dichloromethane in the same manner as regular particulate filters. These extracts were analyzed for Ames activity and the results appear in Table 7.8 as Samples #4, 5, 6, 10 and 11. All activities were unusually high, particularly when expressed as revertants/µg extract.

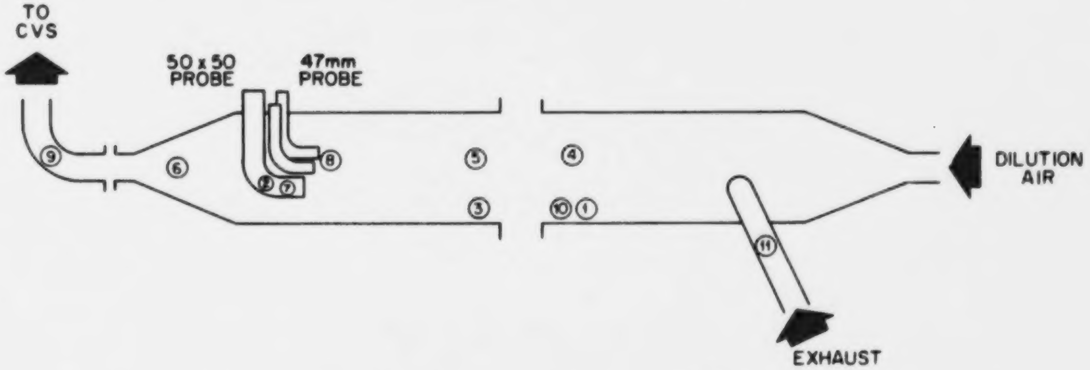


Figure 7.4 Locations of particulate samples removed from the dilution tunnel.

The Ames activities were considerably more uniform when expressed in particulate mass basis. The extractible (%) and the specific activity combined in an inverse fashion to give this result. This finding also suggests that the direct-acting mutagens present may be more closely related in origin to the residue than to the extract portion of the particulate.

The physical character of the particulate changed noticeably moving from the tailpipe connecting tube (Sample #11) to the inlet of the CVS (Sample #9). The particulate deposited in the connecting tube (which was used primarily for Volkswagens) was composed of small, compacted particles which adhered tightly to the tube and had very little extractible matter. Progressing down the tunnel from the area where dilution air enters and the mixture cools, the particulate grows progressively lighter (lower bulk density) and has higher percent extractibles. The sample from the inlet to the CVS contained much material of low density which became airborne when disrupted.

Some of these differences are probably due to temperature and velocity changes occurring within the system. It is also reasonable to assume that erosion of old particulate from the wall occurs concurrently with deposition of fresh particulate. In addition, volatile material in the deposited particulate would tend to move toward the cooler end of the tunnel. This is possibly indicated by the increase in % extractibles noted at the cooler end of the tunnel.

EXPOSURE OF PARTICULATE AND EXTRACT TO DILUTE FILTERED EXHAUST

Introduction

There is a concern in the diesel emission field, about the effects (if any) on particulate collected on a filter from exposure to the gaseous components of the exhaust. Two experiments were conducted to investigate the effects of exposure to dilute exhaust gases on mutagenecity by the Ames TA98(-) assay. In the first experiment, particulate was collected from a 50C driving cycle for varied times and then re-exposed to filtered dilute exhaust gas for varied times. In the second experiment a composite sample of dichloromethane extract was prepared and applied to clean filters, which were then exposed to filtered dilute exhaust gas. Collection of particulate for the composite extract sample for this second experiment entailed repeated vehicle runs throughout a single day, and these individual particulate samples provided an opportunity to determine the variability in specific mutagenesis activity from successive test cycles. These results, while peripheral to the main objective of the study, provide a backdrop against which to consider the results of the exposure tests and are discussed in Section 6.

Vehicle Test Conditions

All tests were performed at a steady 50 mph cruise mode, except that the acceleration and deceleration portions to and from the 50 cruise condition could not be excluded from the particulate collection due to sampling equipment constraints. Dynamometer conditions were as given in Table 3.1.

Exposure of Particulate to Filtered Exhaust

This portion of the test program was performed with Car #5. Particulate was collected during a 50C for 5, 10, 15, and 30 min duration. After completion of particulate collection, the filter was retained in its holder and covered by two unused filters and replaced in the particulate sampling apparatus. A second 50C was then run using this package of three filters. The first filter now collected particulate while the middle filter acted as a back-up to avoid further collection of particulate on the last (original) filter. Table 7.9 shows the time of particulate collection, time of added exhaust exposure, particulate, extract, and Ames results.

TABLE 7.9. EXPOSURE OF PARTICULATE TO DILUTE EXHAUST

Particulate Collection Min	Additional Exhaust Exposure		Part 47mm g/mi	Part 50^2 g/mi	Extract		Ames Activity TA98(-)		
	min	m^3			%	g/mi	$\frac{REV}{\mu gE}$	$\frac{REV}{\mu gP}$	$\frac{REV}{mi}$
5	0	0	0.40	0.58	30.7	0.122	4.5	1.4	5.4
5	5	12.2	0.35	0.41	34.3	0.120	3.9	1.3	4.7
5	10	24.1	0.38	0.48	34.2	0.130	3.8	1.3	5.0
5	15	35.7	0.38	0.43	34.7	0.134	3.7	1.3	5.0
10	0	0	0.35	0.40	3.59	0.127	3.4	1.2	4.4
15	0	0	0.36	0.37	39.9	0.144	2.5	1.0	3.6
15	0	0	0.36	0.39	37.1	0.133	2.4	0.9	3.2
15	0	0	0.36	0.37	36.5	0.133	2.3	0.8	3.0
15	15	34.3	0.37	0.38	39.3	0.145	3.0	1.2	4.4
15	30	66.6	0.35	0.36	39.3	0.138	3.1	1.2	4.3
30	0	0	0.37	0.35	40.	0.147	2.5	1.0	3.6
30	0	0	0.35	0.35	36.8	0.130	2.4	0.9	3.1
30	15	31.0	0.35	0.34	37.9	0.132	4.3	1.6	5.7
30	30	59.5	0.35	0.34	37.8	0.133	2.8	1.0	3.7

In a 50C the 50x50 cm filter must be operated during the acceleration to 50 mph and the deceleration from 50 mph. Therefore, the filter collects particulate from the acceleration and deceleration modes as well as from the 50 mph cruise. This is apparent in Table 7.9 where the 50x50 cm particulate values (g/mi) are significantly higher than the 47 mm particulate values (which do not include the acceleration/-deceleration modes) for the 5 min collection times. The effect diminishes for longer times.

For none of the three particulate collection times was there a significant or consistent change in the extract itself or in its Ames activity. For the 5 min particulate collection case there was a consistent decrease in the activity with exposure. This difference was not large enough to be considered significant. This difference, as well as the lower % extract for 5 min filters, may be attributed to the relatively large effect exerted on these parameters by the particulate collected during the acceleration/deceleration associated with this cycle. The high particulate and Ames activity and low % extractible of the filter used to collect particulate for 5 min with no subsequent exposure may indicate that the vehicle was not completely equilibrated when this sample was collected, since effects of this type have been observed in several cold-start/hot-start comparison experiments reported previously (37, 42).

The 15 and 30 min particulate collection cases show small but non-significant increases in Ames activity which did not relate to exhaust exposure time. Both the mass and percentage of extract show no significant changes as a result of re-exposure to dilute exhaust. Changes in extract can be attributed to the previously mentioned characteristic of the driving cycle.

Gaseous measurements were made on three cycles during the two days that the test was run. These results are given in Table 7.10.

TABLE 7.10. EMISSIONS DATA FROM PARTICULATE EXPOSURE TESTS

PARAMETER	MEAN ± 1 σ
HC	0.28±0.01 g/mi
CO	0.91±0.01 g/mi
NO_x	1.29±0.03 g/mi
CO_2	296±6 g/mi
Fuel Economy	34.1±0.7 mpg

The consistency of the gaseous data above and the 47 mm particulate data in Table 7.10 indicate that particulate collection and subsequent exhaust exposure were performed under consistent dilution tunnel conditions.

Conclusions

The experimental results do not support the hypothesis that the gaseous components of diluted exhaust affected the mutagenic activity of the extract of particulate collected on Pallflex T60A20 media under the conditions of the experiment.

Exposure of Extract Alone to Filtered Exhaust

The extractible material bound to the carbonaceous portion of diesel particulate may be only partially available for reaction with gas phase components while in particulate form. To test for potential reactions between the extract and dilute exhaust, a series of experiments were performed wherein extract obtained from the consecutive tests described above was re-deposited with a solvent carrier on a clean filter. The solvent was dried, leaving the extract laden filter for subsequent exposure to dilute filtered exhaust gas. Approximately 100 mg aliquots of extract were applied to the central portion of a 50x50 cm filter over an area of about 1250 cm^2. As in the particulate exposure tests, these extract carrying filters were covered with two blank filters to isolate the extract filter while exposing the extract to dilute exhaust gas and collecting a corresponding particulate sample. Results for Car #5 and Car #1 are presented separately below.

Car #5 Results--

The three filters containing approximately 100 mg of extract were exposed to dilute filtered exhaust for 5, 15, and 30 min respectively. Normal particulate samples were also collected for 5, 15, and 30 min, and a 15 min particulate sample was also exposed to exhaust for 15 min. The results are shown in Table 7.11.

The three filters with applied extract had Ames responses greater than the three corresponding particulate filters which were exposed with them. The Ames activities of the extracts were, however, lower than the 3.7 revertants/ μg average activity of the extracts used to produce the composite extract. Analysis is complicated by the lack of a zero time exhaust exposure filter with applied extract. Thus, it is not possible to determine what the activity of the extract was immediately prior to exposure or if the activity of the applied extracts was affected by re-extraction.

It is clear that filters 1664, 1663, 1662 do not show a dose-response relationship which would indicate an exhaust exposure effect. Any effect, however, may be

TABLE 7.11. EXPOSURE OF EXTRACT TO DILUTE EXHAUST GAS - CAR #5

Filter	Extract Applied mg	Particulate Collected mg	Particulate Collection Time(min)	Exhaust exposure		Extractibles[a]		Ames rev/ μg
				min	m^3	mg	%	
1664	101			5	16.1	93.9	93.0	2.5
1663	107			15	39.3	102.2	96.4	1.8
1662	99			30	76.5	95.2	96.2	3.0
Pooled extract used to prepare filters 1664, 1663, 1662								3.7
1666	0	13[b]	0[b]	50	131.9	10.9		2.4
1671	0	227	5	0			37.4	1.6
1670	0	530	15	0			40.1	1.3
1667	0	1129	30	0			36.7	1.5
1668	0	582	15	15	39.1		37.5	3.6

a. A blank filter will contribue about 2 mg of extract itself. Therefore, extract weights and percentages are higher than actual.

b. Filter 1666 was run for 50 minutes as a backup filter.

complete by the 5 min exposure time. Filter 1668, which had 15 min exhaust exposure to 15 min of collected particulate, shows enhanced activity as compared to filters 1671, 1670 and 1667 which would seem to indicate that exhaust exposure increases Ames activity. This result does not agree with data shown in Table 7.9.

It is of further interest that filter 1666, which was run for 50 minutes as a backup filter and showed a 13 mg weight increase, had an Ames response greater than that of the extract from the filter which preceeded it in the gas stream. If one multiplies the Ames activity (2.4 revertants/ μg) by the extract weight (1.09×10^4 μg) the result is total revertant count attributable to the filter. For filter 1666 this value is 2.6×10^4 revertants. If a filter contained 100 mg (10^5 μg) extract, the increase in Ames activity from particulate passing through the primary filter and collecting on the extract-exposure filter would be less than $2.6 \times 10^4/10^5 = 0.3$ rev/ μg. This indicates that the filter exposed to filtered exhaust did not change appreciably due to additional material passing through the primary filters.

The data do not indicate that filtered diluted exhaust gas has a substantial effect on the Ames activity of extracted material. The data do not, however, prove that there is no effect. Defects in the experimental design and the small data set do not allow the experiment to give a conclusive answer.

Car #1 Results--

Similar to the Oldsmobile experiments, filters with approximately 100 mg applied extract were exposed to filtered dilute exhaust for 5, 10, and 20 min respectively. Normal particulate filters of 10, 15 and 20 min length were also collected. The results are shown in Table 7.12.

The results for filters 1653, 1652 and 1651 indicate a decrease in Ames activity with increased exhaust exposure. Although the changes may appear significantly large, past experience with this vehicle has indicated that differences of this magnitude occur in the Ames analysis of triplicate runs. Therefore, the three data values alone are not sufficient to substantiate an exhaust exposure effect. Furthermore, all of the Ames values determined in the experiment were significantly lower than the values measured for the extracts comprising the composite (Ave $\pm 1\sigma = 24.8 \pm 6.8$, rev/ μg, Range 12.1 to 33.4). In past tests this vehicle has shown erratic

TABLE 7.12. EXPOSURE OF EXTRACT TO DILUTE EXHAUST - CAR #1

Filter	Extract Applied mg	Particulate Collected mg	Particulate Collected Time(min)	Exhaust exposure[a] Time (min)	m^3	Extractibles[b] mg	%	Ames rev/µg
1653	99	0	0	5	15.6	94.8	95.8	10.0
1652	98	0	0	10	26.5	92.1	94.0	8.4
1651	99	0	0	20	46.2	92.6	93.5	6.9
Pooled extract used to prepare filters 1653, 1652, 1651.								24.8
1660	0	7	0	10	22.8	6.0		1.7
1661	0	10	0	15	38.5	6.9		1.6
1658	0	601	10	0		93.8	15.6	7.1
1659	0	1009	15	0		126.2	12.5	7.3
1656	0	1271	20	0		186.5	14.7	8.3
1657	0	699	10	10	22.0	108.6	15.6	8.4
1654	81			c	566[c]	79.1	97.7	9.5

a. Volume corrected to 20°C.

b. A blank filter will contribute abut 2 mg of extract itself. Therefore, extract weights and percentage are higher than actual.

c. Room air (filtered) drawn through filter overnight at about 20°C.

Ames results with consecutive tests showing large variations in response. It also appears that when this vehicle is operated under 50C conditions, the Ames activity of filters collected consecutively shows a significant increase. This might contribute to the trend observed with filters 1653, 1652 and 1651, as these filters were run in numerical order.

Filters 1658, 1659 and 1656 represent increased particulate collection times. The slight increase in Ames activity with increased collection time is not considered significant. The significant fact is that the average activity of these extracts is 7.6 rev/µg vs. 24.8 rev/µg for filters collected a week earlier. This difference must be predominantly real as the reproducibility of the Ames test is much better than the difference would suggest. Filter 1657 represents 10 min of exhaust exposure to a filter with 10 min of particulate collection. The change in Ames activity is not significant.

Filter 1660 was run as a blank, i.e., covered by two filters and exposed as were the filters with extract. Filter 1661 was run as a back-up to filter 1659. Both filters showed a small increase in weight which was mainly extractible. The extracts showed Ames results of 1.7 and 1.6 rev/µg respectively. These values are much lower than those of primary filters and indicate that material of higher Ames activity is associated with particles collected on the primary filter. This is the reverse of the results for the Oldsmobile tests in which the primary filters had lower activities than the backups.

Although an apparent dose-response decrease in Ames activity for increase exposure to dilute filtered exhaust has been observed, the inherent Ames activity variability of extract from this vehicle makes the result very uncertain.

Discussion

The results do not constitute a definitive experiment on the reactivity of extract, on or off particulate. Variations in Ames mutagenicity arising from vehicle parameters that are only poorly understood complicate attempts to isolate any interactions between dilute exhaust gases and extract. If results for a single experiment were all that one had, a dramatic effect could be reported. When a battery of tests are considered, the picture is not always consistent. The fact that major increases in Ames mutagencity were not generally observed with increased particulate collection time, particulate re-exposure, or extract re-exposure suggests that the particulate sample conditions are not the main cause of the observed activities. The several cases of observed decreases in Ames activities with sample exposure is deserving of further investigation.

An additional consideration in the study of sampling effects on mutagenic activity is the presence of dilution tunnel debris. We have assayed extract from tunnel scrapings, and found, like others, that this material exhibits elevated activity - about 30 rev/μg in our case. Thus we have a sampling system that is coated with material of considerably higher activity than the samples we wish to measure. If this debris re-entrains (and it does) the activity will be increased. For instance, a filter with extract exhibiting 4.3 rev/μg started with a total particulate mass of 1.213g. Assuming a tunnel debris activity of 30 rev/μg, and an activity of 2.5 rev/μg for particulate uncontaminated by tunnel debris, a contaminated sample of 4.3 rev/μg would require the following amount of debris:

$$4.3 = 2.5\,(1.213\text{-Tunnel Particulate}) + 30\,(\text{Tunnel Particulate})$$
$$\text{Tunnel Particulate} = 0.05\text{ g}$$

Thus only 50 mg of tunnel debris could raise the activity from 2.5 to 4.3 rev/μg for a total sample size of over 1200 mg particulate. The exhaust tubing connecting the vehicle to the dilution tunnel contains debris of significantly higher activity than the tunnel itself, although the extractible content from this source is much lower. Thus a significantly smaller debris contribution from this source would cause the same change in observed specific activity.

Thus, mutagen sampling artifacts can occur by means other than exhaust gas exposure during the time scale of particulate collection. Elevated specific activities of tunnel and connector pipe debris suggest a long-term change in extract character not readily seen in short-term collection tests.

EXPOSURE OF PARTICULATE AND EXTRACT TO SUNLIGHT

In the late summer of 1981, three 50 x 50 particulate filters from Car #5 were collected from successive 15 min 50C tests. One filter (#1561) was kept at room conditions for two days (no light) and extracted. A second filter (#1560) was left in the filter holder. The third filter (#1562) was extracted immediately after collection and the extract alone redeposited on a fresh 50 x 50 filter as previously described. The particulate filter and extract laden filter were then set outside in bright sunlight for portions of two days (8 hours total exposure). Following this time, all three filters were extracted and assayed with tester strain TA98(-). The dose/response plots for these samples, and those from a comparable 50C sample from an in-use test on this vehicle near the same time are shown for two dose ranges in Figure 7.5. The specific activities of these samples are fairly low, and this is consistent with the in-use test results for this vehicle.

Examination of the three plots for samples 1560, 1561, and 1562, shows a response below 25 μg dose. For the sample of extract exposed to sunlight (1562) this initial response is followed by a general lack of consistent response at higher doses. This

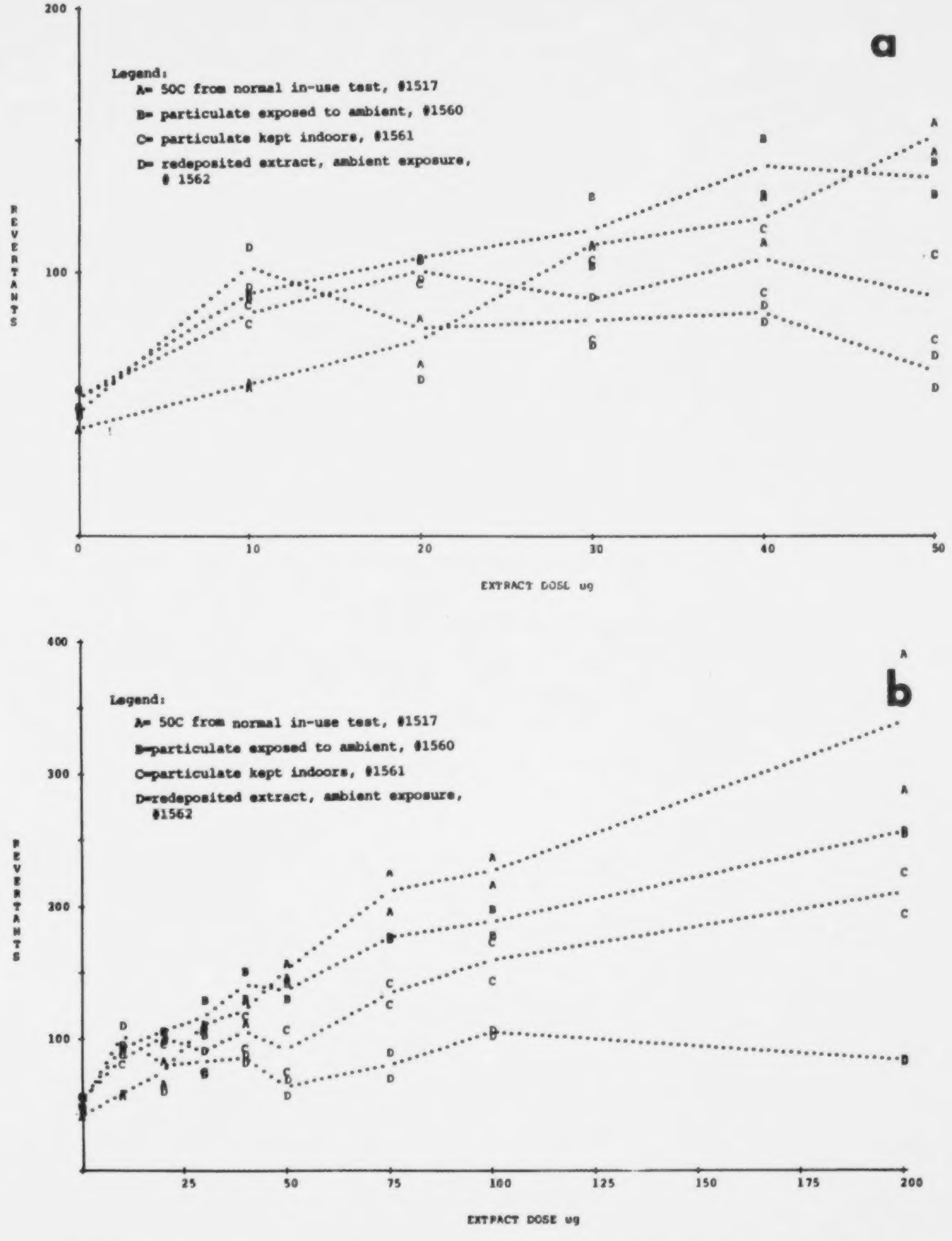


Figure 7.5 Dose-response curves for exposure of particulate and extract to sunlight: (a) 0-50 μg dose range, (b) 0-200 μg dose range.

may be due to the loss of direct acting mutagens or the formation of toxic agents during exposure. The particulate exposed to sunlight exhibits an extract dose/response plot not dissimilar to the comparison particulate samples unexposed to sunlight. The slightly higher extract response for the sunlight exposed particulate may be accounted for by the slight decrease in extractible % for the sunlight exposed sample.

Although these results from a single experiment must be viewed cautiously, they do indicate the relative sunlight exposure changes between particle-bound and extracted direct-acting mutagens for this one test condition.

COLD AMBIENT PARTICULATE TESTS

Mid-project review of the Ames mutagenicity data from various vehicle test cycles showed the FTP to be frequently somewhat elevated in comparison to other cycles. Since the FTP was the only test cycle with an overnight vehicle soak as part of the test, this aspect of vehicle conditioning was considered a possible factor. A series of particulate emission, extract and bioassay tests were performed in the winter of 1981 on Car #1(VW Rabbit) to evaluate the effect of vehicle soak temperatures.

In project FTP testing particulate from the three FTP bags was collected on a single filter. Bag I and Bag III have an identical 505 second driving schedule, Bag I beginning the FTP after overnight laboratory vehicle soak, and Bag III commencing after a 10 min hot-soak subsequent to Bag II. For the special tests reported in this section the Bag I (or Bag III) driving schedule was used to collect separate particulate samples for only the appropriate 505 second test, in contrast to a normal FTP which provided only a composite particulate sample from Bags I, II, and III. Two additional samples were obtained by soaking the vehicle overnight at winter ambient (outdoor) conditions and then testing at laboratory conditions to obtain cold-ambient soak Bag I and Bag III samples. Thus the four vehicle conditions tested were: 1)Bag I after overnight ambient cold soak; 2)Bag III hot start following condition (1); 3)Bag I after normal overnight vehicle soak in laboratory; 4)Bag III following condition (3). Continuous temperature monitoring was set up for a)overnight ambient, b)vehicle injection fuel line, and c)vehicle crankcase lubricating oil.

Table 7.13 gives the results of duplicate tests at each of the four conditions. The test result for condition (4) above, normal hot-start (Bag III), was used as the base condition for comparison results. The emission parameters listed are all given as ratios to the base condition results. The mean temperature values given result from fairly large variations in temperature between the beginning and end of the particular test, and thus should be considered as only rough guides to the temperature histories encountered.

Examination of Table 7.13 shows the following for successively lower temperatures (lower rows in the Table 7.13): 1)total particulate increased by 18-74% over the base, 2)extractible expressed as a % of total particulate dropped by 13-36%, 3)extract as a mass emission showed little change ±13%, 4)residue accounted for the majority of increase in total particulate, showing an increase from 24-92% over the base condition, 5)the various bioassay measures show increased bioactivity ranging from 230% to 400%, depending on computation choice. Braddock (42) in contrast found the bioactivity to decrease with decreasing temperature.

The increase in residue corresponds more closely to the increases in bioactivity

TABLE 7.13. VW COLD-START PARTICULATE AND AMES ACTIVITY COMPARISONS*

	Mean Temperature - °C				Extract			Revertants - TA98(-)		
Vehicle Test Condition	Overnight Soak	Injector Fuel Line	Crankcase Lube	Particulate (g/mi)	(%)	(g/mi)	Residue (g/mi)	Rev/μ Extract	Rev/μg Part.	10^5Rev/mi
4 = Base Condition-Normal FTP Bag III Hot Start	20	25	90	0.34	24.8	0.084	0.26	5.8	1.44	4.9
					Results below are ratioed values to the base condition in each column.					
2 = Bag III Hot Start following cold ambient test	0	18	98	1.0	0.87	0.87	1.03	1.5	1.3	1.3
3 = Normal FTP Bag I after overnight lab soak test	20	21	48	1.18	0.79	0.93	1.24	1.8	1.4	1.7
1 = FTP Bag I after overnight ambient soak	0	5	38	1.74	0.64	1.11	1.92	3.6	2.3	4.0

*Average results for two duplicate tests at each condition.

than any other emissions parameter measured. The injector fuel line temperature corresponds to the observed emission changes more closely than other temperature measurements. These results suggest the need for a definitive experiment with controlled variation in fuel temperature and corresponding measurement of particulate, extract, residue, and bioactivity. If fuel temperature does effect the combustion/formation of trace bioactive species, the unknown variation in injector fuel line temperature during laboratory vehicle testing could account for some of the apparently random bioactivity results, since the fuel temperature could be affected by fuel recirculation to the fuel tank, and fuel volume in the tank. The correspondence of residue increase to the increased bioactivity is similar to findings reported elsewhere in this report connecting residue and not extract to the bioactivity of extract samples.

SECTION 8

CHEMICAL CHARACTERIZATION OF EXTRACTS

INTRODUCTION

The objective of this work was to isolate, identify, and quantify the chemical substances responsible for mutagenic activity of the organic extracts of diesel emission particulates.

Diesel particulates are highly respirable (43) and may constitute a significant inhalation health hazard to the human population. The chemical composition of the organic extractible matter of the particulates is extremely complex. When this work was initiated in 1979 there was very little published information about the identity of possible mutagens in diesel particulate extracts. Polynuclear aromatic hydrocarbons (PAH) were the major class of organic carcinogens/mutagens whose presence had been established (44-46) in extract samples from diesel particulates. Both parent PAHs and their alkyl derivatives were detected in these studies. Subsequent studies utilizing the Ames Salmonella mutagenesis assay and other short-term bioassay methods have indicated that diesel particulate extracts possess significant mutagenic activity even in the absence of mammalian enzymes (47, 48), suggesting mutagenic contributions from compounds other than PAHs, which require metabolic activation to exhibit mutagenicity.

The approach adopted for this study was to integrate the Ames microbial mutagenesis assay as a biological monitor with chemical fractionation, identify the mutagenic fractions for detailed structural characterization of the constituents by several complementary techniques, and assess the mutagenic contribution of the PAHs present in the extract samples.

This section is a brief account of the significant parts of the work carried out during 1979-June 1981. The report was not written in a descriptive manner, since more detailed accounts of the results obtained are summarized in publications that have originated from this work (References 48 to 52).

RESULTS AND DISCUSSION

Particulate Sample Collection

The project was initiated by generating a few large project-reference samples for characterization and bioassay work to proceed in parallel with subsequent in-use vehicle testing. The three vehicles used to generate these samples were a Mercedes-Benz 300-D obtained from EPA in Ann Arbor, a diesel Rabbit (Car #1), and a diesel Oldsmobile (Car #5). Particulate samples for this characterization/bioassay effort were collected by the sample equipment and general procedures as described earlier. The daily testing sequence was not the same as used for the in-use vehicle study, and involved only two driving cycles. An FTP began each day of sample collection during which one 50 cm x 50 cm filter was collected. With the FTP as a warm-up the rest of the testing day consisted of 24 HFET cycles broken into 8 groups of three HFET cycles per single 50 cm x 50 cm filter. One day of testing thus generated one FTP and eight HFET 50 cm x 50 cm filters.

Two fuels were used for sample collection from the Mercedes 300-D. A 750 liter lot of EPA control fuel from EPA/RTP was used first to generate filters to be shipped to EPA/RTP for subsequent extraction and analysis. All other large particulate samples in these three vehicles were obtained using a 7500 liter lot of project reference fuel in underground storage at AEL. At the beginning of each large sample collection each vehicle was serviced with fresh oil and oil filter. Oil samples were collected from the vehicle at the conclusion of the sample collection.

Gaseous emissions were measured for one FTP and one HFET approximately every fifth day of sample collection. Particulate emissions were likewise measured by the 47 mm probe filters described earlier. The individual 50 cm x 50 cm filters were extracted by the same procedure as previously described and the extracts from all filters from each cycle pooled to yield one composite sample. The FTP and HFET filters were treated separately to provide a comparison between vehicle test cycles.

Table 8.1 contains the summary information on these large samples to the point of their bioassay and chemical characterization analyses. Table 8.1 also identifies each of these samples by codes which reference these samples in the chemical analysis portions of this report. In total these samples represent over 13,000 dynamometer miles performed on 50 days of laboratory testing and using in excess of 450, 50 cm x 50 cm filters.

TABLE 8.1. SUMMARY OF LARGE PARTICULATE SAMPLES FOR CHEMICAL AND BIOASSAY CHARACTERIZATION

					Large Particulate Sample			Emissions (g/mi)					
Vehicle	Fuel	Oil	Sample Identification	Driving Cycle	Particulate (g)	Extract (g)	% Extract	HC	CO	NO_x	Part	MPG	Comments
Mercedes-Benz 300-D	EPA Reference	Castrol 20W-50 SE-CC	S2	FTP	23.1	2.1	9.1	0.22	1.11	1.74	0.63	21.7	Vehicle shipped from EPA, Ann Arbor
			L2	HFET	255.0[a]	19.49[a]	8.5[b]	0.12	0.82	1.52	0.39	28.0	Filters shipped to EPA/RTP for extraction
Mercedes-Benz 300-D	AEL Reference	Castrol 20W-50 SE-CC	L3	FTP	5.9	0.54	9.2	0.22	1.08	1.88	.64	21.8	
			L4	HFET	53.2	6.1	11.5	0.11	0.79	1.57	0.36	30.0	
Rabbit	AEL Reference	Castrol 20W-50 SE-CC	L5	FTP	4.3	0.98	22.8	0.37	0.93	0.95	0.32	41.0	Car #1
			S1	HFET	53.76	15.58	29.0	0.18	0.74	0.90	0.28	51.9	
Oldsmobile	AEL Reference	Castrol 10-30 SE-CC	L7	FTP	11.52	1.99	17.3	0.48	1.60	1.83	0.79	21.1	Car #5
			S3	HFET	115.1	27.5	23.9	0.23	0.88	1.44	0.31	31.3	Sample also used for project bioassay std.

[a] Only 229.45g of particulate were extracted.
[b] Average of eleven extractions of 15 filters (~ 20g) each, σ = 0.74.

Fractionation of Particulate Extracts

The extracts were fractionated by a two-step procedure. The first step was a liquid-liquid partitioning by which acidic, basic and neutral compounds were separated as shown in Figure 8.1a. The acidic fraction showed the highest specific activity profile of the three fractions, as shown in Figure 8.2 and is discussed in Reference 48. The neutral fraction comprised the largest fraction (90-95%) by extract mass for all three composite samples studied. This neutral fraction was subfractionated by silica gel preparative adsorption chromatography described in Reference 48 and Figure 8.1b.

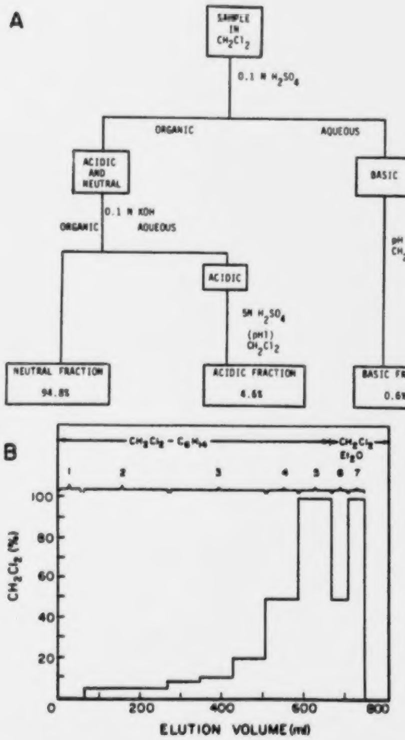

A
SAMPLE IN CH_2Cl_2
0.1 N H_2SO_4
ORGANIC
AQUEOUS
ACIDIC AND NEUTRAL
BASIC
0.1 N KOH
ORGANIC
AQUEOUS
pH 10-11 CH_2Cl_2
ACIDIC
5M H_2SO_4 (pH1) CH_2Cl_2
NEUTRAL FRACTION 94.8%
ACIDIC FRACTION 4.6%
BASIC FRACTION 0.6%
B
$CH_2Cl_2 - C_6H_{14}$
CH_2Cl_2 Et_2O
1
2
3
4
5
6
7
100
80
60
40
20
0
200
400
600
800
CH_2Cl_2 (%)
ELUTION VOLUME (ml)

Figure 8.1 (A) Fractionation of diesel emission particulate extracts. (B) Elutant profile for chromatographic fractionation of neutral diesel particulate extract. (48)

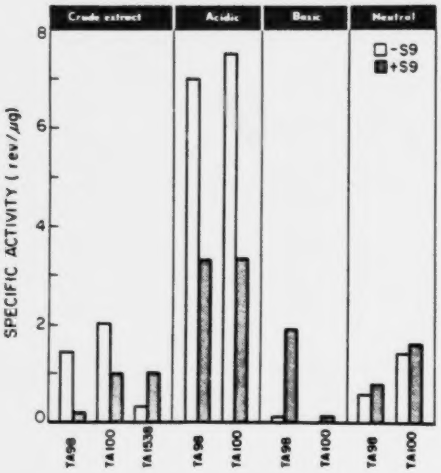


Figure 8.2 Mutagenicity of diesel particulate extract sample S-1 and its fractions (Car #1). (48)

Several changes were subsequently introduced to the procedure. The samples were introduced to the top of the column coated on prewashed and dried sea sand. The column was sequentially eluted with solvents of increasing polarity as shown in Figure 8.3. All fractions were concentrated in Kuderna-Danish evaporators to about 1 ml and transferred to tared test tubes. The remaining solvent was evaporated on an "Evapo-mix" under gentle vacuum at 30°C and weighed. In previous work, we used a small amount of silica gel to introduce the sample but this resulted in poor recovery of certain compounds. Use of sand improved recovery of these compounds. The elution volume of the PAH fraction, designated as subfraction C2, was determined by the elution volumes of fluorene and coronene under identical chromatographic conditions.

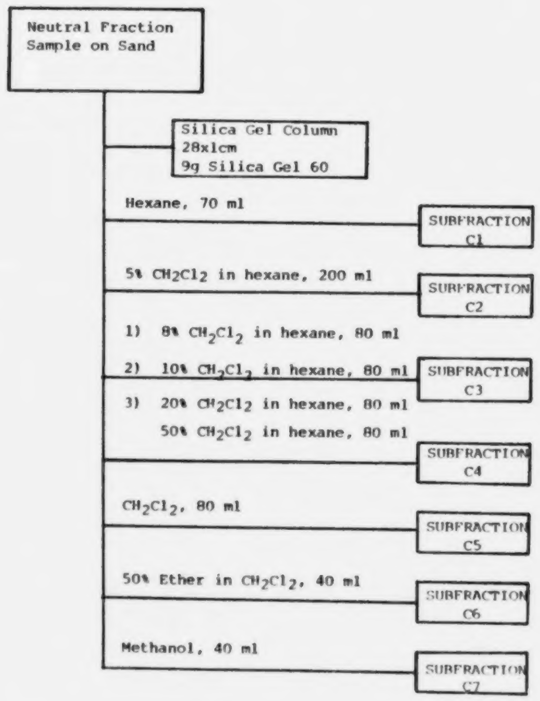

Neutral Fraction
Sample on Sand
Silica Gel Column
28x1cm
9g Silica Gel 60
Hexane, 70 ml
SUBFRACTION C1
5% CH_2Cl_2 in hexane, 200 ml
SUBFRACTION C2
1) 8% CH_2Cl_2 in hexane, 80 ml
2) 10% CH_2Cl_2 in hexane, 80 ml
SUBFRACTION C3
3) 20% CH_2Cl_2 in hexane, 80 ml
50% CH_2Cl_2 in hexane, 80 ml
SUBFRACTION C4
CH_2Cl_2, 80 ml
SUBFRACTION C5
50% Ether in CH_2Cl_2, 40 ml
SUBFRACTION C6
Methanol, 40 ml
SUBFRACTION C7

Figure 8.3 Silica gel fractionation of neutral diesel particulate extract.

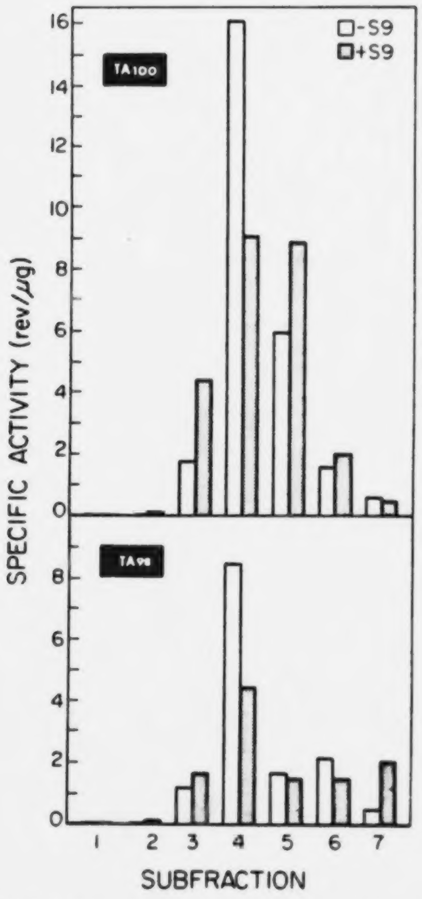


Figure 8.4 Distribution of mutagenicity among sample S-1 subfractions of neutral diesel particulate extract of Car #1. (48)

Final elution with methanol was essential to obtain the last traces of some polar components, not all of which eluted completely with ether.

All subfractions (C1-C7) were bioassayed with the tester strains TA98 and TA100 at six or more dose levels. Mutagenicity distributions among subfractions of the neutral fraction of sample S1 are shown in Figure 8.4. The trend in mutagenic potency of the subfractions did not change as a result of modifications in subfractionation procedure. The PAH subfraction C2 showed only marginally positive activity in the presence of S-9 for all three composite samples. Subfraction C4 had the highest specific activity for all three composite samples. The subfraction C5 also had considerably high mutagenic activity. Subfractions C3, C6, and C7 showed some mutagenic activity. The chemical characterization work emphasized subfractions C2 (PAH subfraction), C3, C4, and C5.

Characterization of the PAH subfraction C2: PAHs are a well-recognized family of carcinogens and mutagens that require metabolic activation for expression of mutagenicity. Many members of this family have long been considered responsible for carcinogenicity of combustion effluents. It was shown in this work that PAHs (parent and alkyl substituted) have only marginal contribution to the mutagenicity of diesel particulate extract samples.

The major problem in PAH analysis is separation and conclusive identification of individual isomeric compounds, since carcinogenic properties of PAHs are isomer-specific. Many PAH reference standards are not available, making conclusive identification of the isomers especially difficult. In the present work, glass capillary gas chromatography, alone and in conjunction with mass spectrometry, and high performance liquid chromatography coupled with rapid scanning ultraviolet spectrometery were utilized for PAH identification in diesel emission particulate extract samples. Much of the work on sample S1 has been described in References 49, 50 and 51.

Gas chromatographic method using an SE-54 coated glass capillary column gave excellent separation of many isomeric PAHs, e.g., benzo(a)anthracene and chrysene, benzo(b)fluoranthene and benzo(k)fluoranthene, and benzo(e)pyrene and benzo(a)pyrene. Separation of these groups of PAHs is important since some are moderate to strong carcinogens, whereas others are relatively innocuous. A chromatogram of 21 PAHs is shown in Figure 8.5. A gas chromatographic profile of the PAH subfraction S1-C2, typical of the PAH subfractions from diesel extract samples, is shown in Figure 8.6A. The major peaks identifiable by comparing their retention times with standard PAHs are phenanthrene, anthracene, fluoranthene and pyrene. Minor components could not be identified with confidence from their retention time alone. Gas chromatography/mass spectrometry of the same sample enabled characterization of over forty PAHs as tabulated in Table 8.2. Total ion chromatograms (GC/MS) of this and another sample are given in Figures 8.7 and 8.8.

An HPLC method was developed to preconcentrate the toxicologically significant, higher-molecular weight PAHs, which were present in low concentration only. A gas chromatographic profile of an HPLC fraction enriched with low molecular weight PAHs by this method is shown in Figure 8.6b. Additional confirmation for identity of the major PAHs was obtained by measuring a complete UV spectrum of each HPLC separated PAH. Presence of anthracene, phenanthrene, fluoranthene, and pyrene were unequivocally confirmed this way. The spectra and HPLC chromatograms are shown in Figures 8.9 and 8.10. The constituents of the HPLC fraction of S1-C2 were also confirmed; the HPLC profile and a number of UV spectra are given in Figures 8.11a

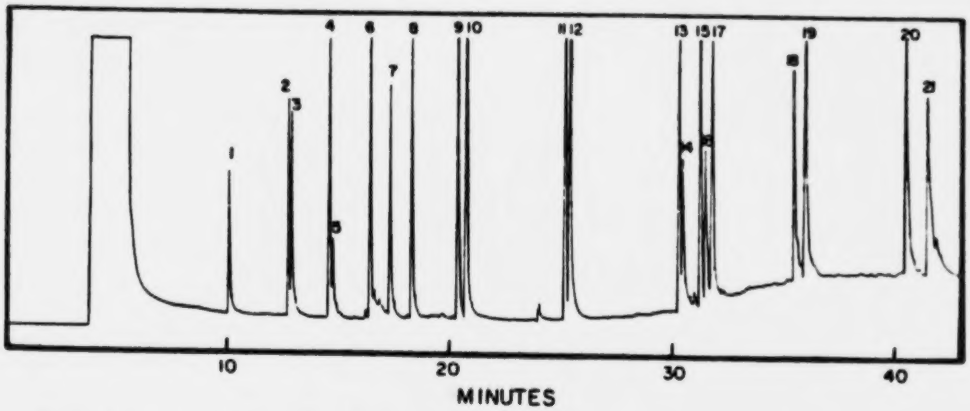


Figure 8.5 *Gas chromatogram of a mixture of PAH standards. GC conditions: 40-m × 0.35-mm id SE54 glass capillary column; flame ionization detector; temperature 100°C for 2 min, programmed to 170°C at 10°/min, to 209° at 3°/min, to 265°C at 7°/min, to 290°C at 8°/min. Peak identities: 1, fluorene (3 ng); 2, phenanthrene (3 ng); 3, anthracene (6 ng); 4, 2-methylphenanthrene (6 ng); 5, 2-methylanthracene (6 ng); 6, 3,6-dimethylphenanthrene (6 ng); 7, fluoranthene (3.6 ng); 8, pyrene (6 ng); 9, benzo[*a*]*fluorene (12 ng); 10, benzo[*b*]*fluorene (12 ng); 11, benzo[*a*]*anthracene (15 ng); 12, chrysene (12 ng); 13, benzo[*b*]*fluoranthene (12 ng); 14, benzo[*k*]*fluoranthene (12 ng); 15, benzo[e]pyrene (12 ng); 16, benzo[a]pyrene (8.1 ng); 17, perylene (12 ng); 18,* dibenz[a,h]-*anthracene (30 ng); 19, benzo[*ghi*]perylene (30 ng); 20, 1,2,3,4-dibenzopyrene (60 ng); 21, coronene (30 ng).* (50)

TABLE 8.2 - COMPOUNDS CHARACTERIZED BY EI GC/MS OF SAMPLE S1-C2 (50)

Scan No.	Compound
539	Methylfluorene
609	Phenanthrene
644	Dimethylfluorene
656	Dimethylfluorene
670	Dimethylfluorene
680	Methyldibenzothiophene
703	Methyldibenzothiophene
724	Methylphenanthrene/-anthracene
729	Methylphenanthrene/-anthracene
751	Methylphenanthrene/-anthracene
754	Methylphenanthrene/-anthracene
745	Cyclopenta[def]phenanthrene
789	C_2-Alkyldibenzothiophene
806	C_2-Alkyldibenzothiophene
814	2-Phenylnaphthalene
830	C_2-Alkylphenanthrene/-anthracene
841	C_2-Alkyldibenzothiophene
853	C_2-Alkylphenanthrene/-anthracene
860	C_2-Alkyldibenzothiophene
865	C_2-Alkylphenanthrene/-anthracene
885	C_2-Alkylphenanthrene/-anthracene
911	C_2-Alkylphenanthrene/-anthracene
916	Fluoranthene
945	Acephenanthrylene/aceanthrylene
980	Pyrene
1032	C_3-Alkylphenanthrene/-anthracene
1041	C_3-Alkylphenanthrene/-anthracene
1057	C_3-Alkylphenanthrene/-anthracene
1064	C_3-Alkylphenanthrene/-anthracene
1077	Methylpyrene/-fluoranthene
1114	Benzo[a]fluorene
1143	Benzo[b]fluorene
1174	Methylpyrene/-fluoranthene
1184	Methylpyrene/-fluoranthene
1345	Benzo[ghi]fluoranthene
1353	Acepyrene
1434	Chrysene, benzo[a]anthracene, triphenylene
1724	Benzo[b,j,&k]fluoranthene
1775	Benzo[a]pyrene, benzo[e]pyrene

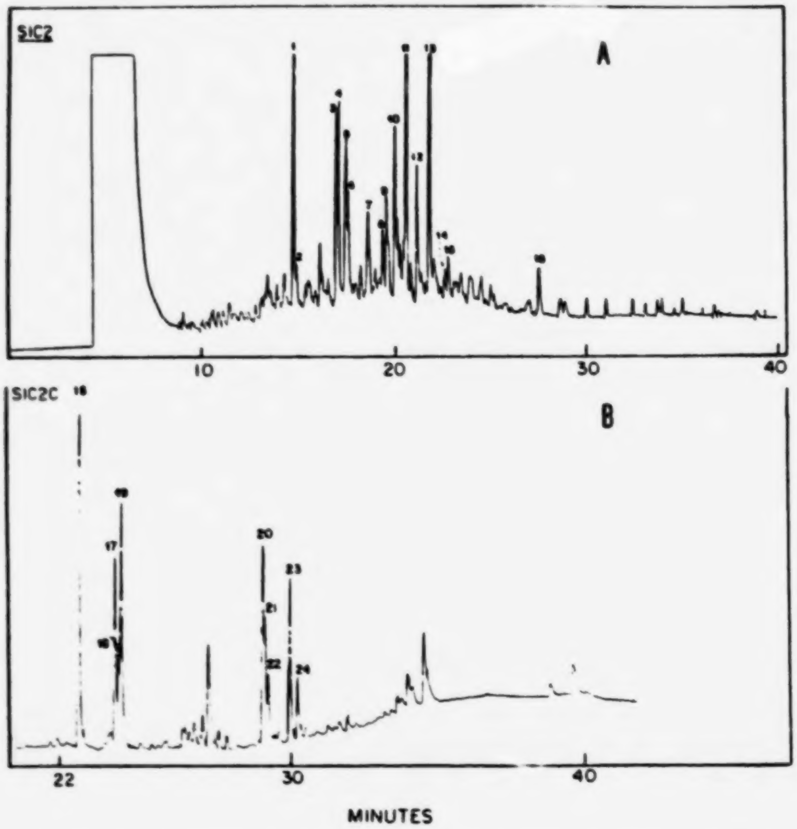


Figure 8.6 *Gas chromatogram of A, PAH fraction of diesel particulate extract (S1-C2) and B, its HPLC subfraction C (S1-C2). GC conditions: 45-m × 0.35-mm id SE54 glass capillary column; flame ionization detector; temperature, 110°C for 2 min, programmed to 170°C at 10°/min, to 212°C at 3°/min, to 278°C at 8°/min. Peak identities: 1, phenanthrene; 2, anthracene; 3–6, methylanthracene/-phenanthrene; 7, 2-phenylnaphthalene; 8–10, dimethylanthracene/-phenanthrene; 11, fluoranthene; 12, aceanthrylene/acephenanthrylene; 13, pyrene; 14–15, trimethylanthracene/-phenanthrene; 16, benzo[ghi]fluoranthene; 17, benzo[a]anthracene; 18, triphenylene; 19, chrysene, 20, benzo[b]fluoranthene; 21, benzo[j]fluoranthene; 22, benzo[k]fluoranthene; 23, benzo[e]pyrene; 24, benzo[a]pyrene.* (50)

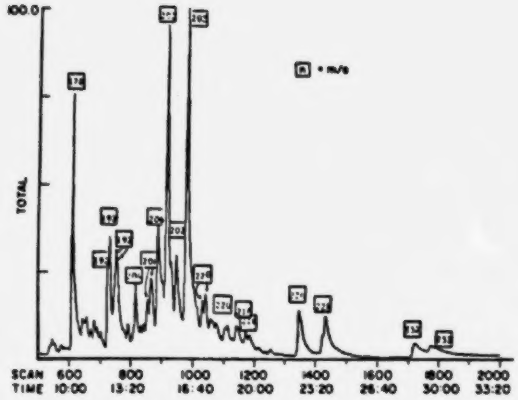


Figure 8.7 Total ion chromatogram of the PAH fraction SI-C2. (50)

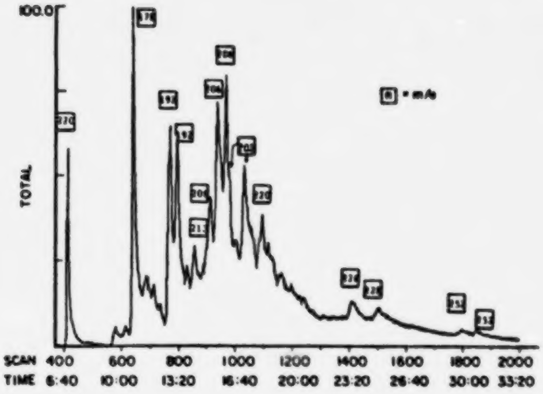


Figure 8.8 Total ion chromatogram of the PAH fraction S2-C2. (48)

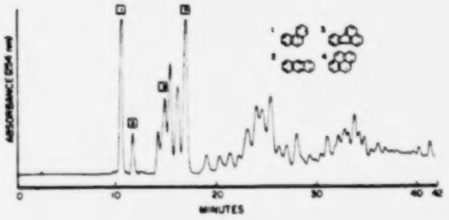


Figure 8.9 HPLC profile of PAH fraction of extract sample S-1 from Car #1. (49)

HPLC condition: 4.6-mm x 25-cm Zorbax ODS column; MeOH/H_2O (84/16); 1.6 ml/min; linear gradient to 100% MeOH (20 min) started after 20 min. (49)

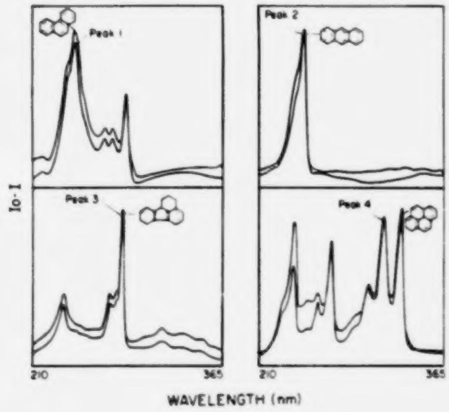


Figure 8.10 Ultraviolet spectra of HPLC eluates of PAH fraction of extract from Car #1. (49)

and 8.11b.

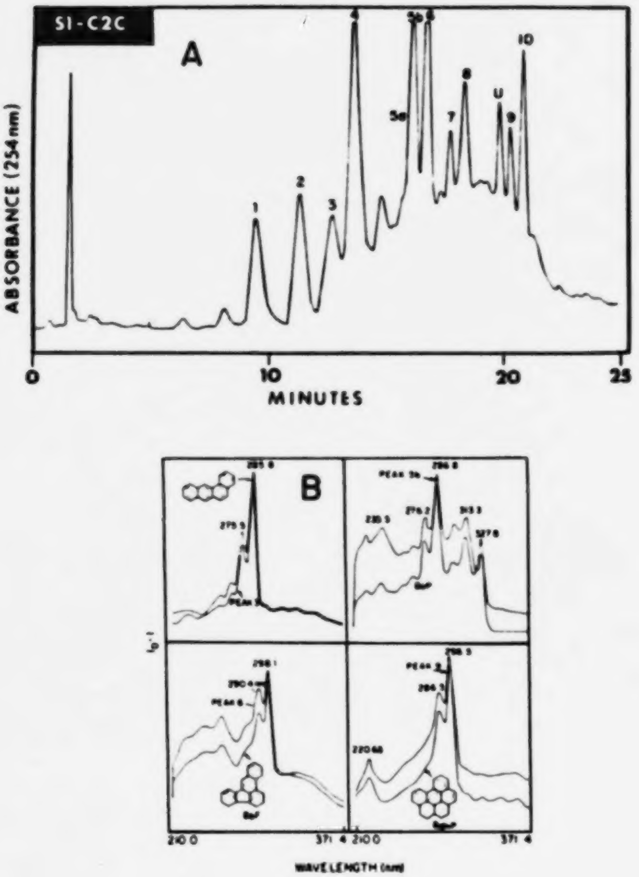


Figure 8.11 (A) HPLC profile of high-molecular-weight PAH fraction of sample S-1 extract of Car #1. (B) UV spectra of HPLC eluates. (51)

Column: HC-ODS (25 cm x 2.6 mm id); mobile phase, 60% MeCN-H_2O for 5 min, linear gradient to 100% MeCN in 10 min.; flow rate, 1.0 ml/min.

PAH subfractions of diesel particulate extract samples (S2 and S3) from two other vehicles gave similar profiles. Characterization was performed by capillary GC, capillary GC/MS and by HPLC/UV spectrometry.

Characterization of Mutagenic Subfractions

Subfraction C4, representing 2.3-3.8% by mass of the neutral fraction, had in general the highest specific mutagenic activity, accounting for 42-52% of the direct-activity mutagenicity of the neutral fractions. Subfraction C5 comprised 3.7-4.8% of the neutral fraction by mass and had the second highest specific activity, accounting for 13-20% of the mutagenicity of the neutral fractions. The GC/MS characterization of subfractions C4 and C5 of sample Sl are discussed, and details are described in Reference 52.

Bioassay results clearly indicated the presence of direct-acting mutagens in these subfractions, although promutagens were presumably present as well. The chromatographic isolation procedure suggested that these fractions contained compounds more polar than parent and alkyl substituted PAHs. The chemical manipulations involved in the preparation of the subfractions also suggested that the mutagens were stable chemicals and not reactive alkylating agents.

Glass capillary GC with flame ionization detection demonstrated the enormous complexity of these samples. Since possible identities of the constituents were unknown, chromatographic conditions could not be optimized, and structural information in the constituents of the subfractions were thus obtained by capillary gas chromatography-mass spectrometry sample examination under EI and CI conditions. Thorough searches of the reconstructed ion chromatograms were made to identify the mass spectra of the maximum number of compounds possible. Interference-free spectra were obtained by using computer-assisted techniques.

The total ion chromatogram of subfraction C4 is shown in Figure 8.12. A number of alkyl fluorenones were identified in this subfraction. These included isomeric methyl fluorenones, C_2-alkylfluorenones, C_3-alkylfluorenones, and C_4-alkylfluorenones. Mass spectral characteristics of these compounds are discussed in Reference 52. While other structural possibilities cannot be totally discounted for these compounds, evidence strongly indicates that most of these compounds are indeed alkylfluorenones. Additional evidence for these structural assignments have since been obtained by HPLC/UV spectrometry. Benzo(a)fluorenone was also a major constituent of this fraction. A list of compounds characterized in this fraction is given in Table 8.3.

Figure 8.13 shows a total ion chromatogram of subfraction C5 of sample Sl. Some important constituents of this fraction are 4H-cyclopenta(def)phenanthrene-4-one, several isomers of 6H-benzo(cd)-pyrene-6-one, methylanthraquinone/phenanthrenequinone, anthracene-and phenanthrene-9-carboxaldehyde, 9-fluorenone, and 7H-benz(de)anthracene-7-one. A complete list of compounds identified in this subfraction by GC/MS is given in Table 8.4. Mass spectral characteristics in support of the structural assignments are also discussed in Reference 52.

Recently the possible presence of mutagenic nitro-PAHs, particularly nitropyrene, has received a great deal of attention. We were not able to detect any nitropyrene in subfractions C4 and C5 of Sample Sl by GC/MS. However, in low concentration, nitro-PAHs can go undetected by full-scan mass spectrometry particularly when operating conditions are not optimized for such compounds. Subfraction C3 of this sample has been found by HPLC/MS to contain nitroanthracene/phenanthrene.

In two other composite samples S2 and S3, we have confirmed the presence of 1-nitropyrene by HPLC/MS (EI and CI) and HPLC/UV spectrometry. In addition, several other nitro-PAHs were detected by HPLC/MS in subfraction C3 of S2. These are nitroanthracene/phenanthrene, methylnitroanthracene/phenanthrene, and methylnitropyrene/phenanthrene.

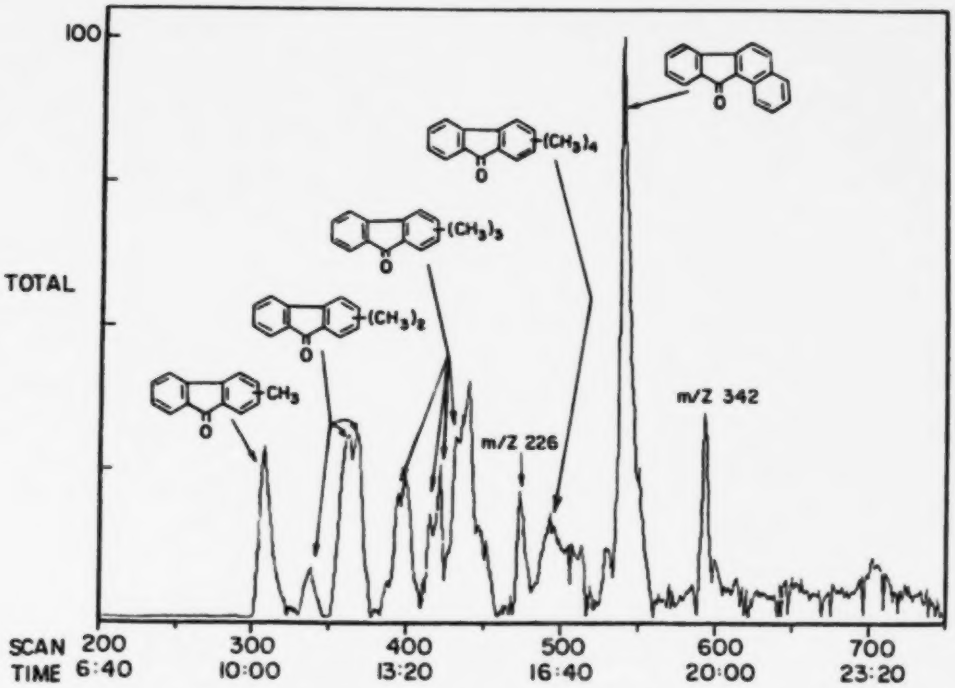


Figure 8.12 Total ion chromatogram (EI) of subfraction 4. (52)

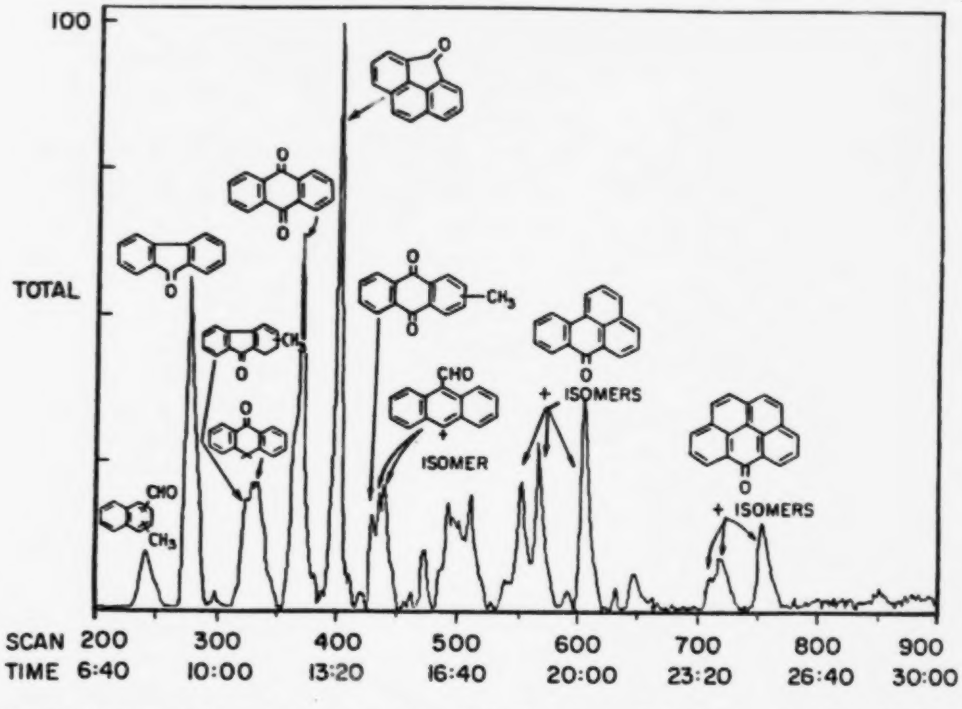


Figure 8.13 Total ion chromatogram (EI) of sample S-1 subfraction 5. (52)

TABLE 8.3 - COMPOUNDS CHARACTERIZED BY GC/MS IN SUBFRACTION 4 (52)

scan no.	EI parent peak	compd
308	194	methyl-9-fluorenone
338	208	C_2-alkyl-9-fluorenone
363	208	C_2-alkyl-9-fluorenone
368	208	C_2-alkyl-9-fluorenone
394	222	C_3-alkyl-9-fluorenone
400	204	4*H*-cyclopenta[*def*]phenanthren-4-one
415	222	C_3-alkyl-9-fluorenone
422	222	C_3-alkyl-9-fluorenone
431	222	C_3-alkyl-9-fluorenone
433	212	9*H*-thioxanthen-9-one
438	206	anthracene/phenanthrene-9-carboxaldehyde
440	218	hydroxypyrene/fluoranthene
452	236	C_4-alkyl-9-fluorenone
473	226	C_2-alkylnaphthofurancarboxaldehyde
475	236	C_4-alkyl-9-fluorenone
488	226	unidentified, hydroxy – *m/z* 210
492	236	C_4-alkyl-9-fluorenone
497	220	methylanthracene/phenanthrene-carboxaldehyde
539'	230	benzo[*a*]fluorenone
594	342	unidentified

TABLE 8.4 - COMPOUNDS CHARACTERIZED BY GC/MS IN SUBFRACTION 5 (53)

scan no.	EI parent peak	compd
245	170	methylnaphthaldehyde
276	180	9-fluorenone
284	184	C_2-alkylnaphthaldehyde
328	194	methyl-9-fluorenone
332	194	anthrone/phenanthrone
365	196	9*H*-xanthen-9-one
370	208	anthraquinone
400	204	4*H*-cyclopenta[*def*]phenanthren-4-one
436	206	anthracene/phenanthrene-9-carboxaldehyde
441	206	anthracene/phenanthrene-9-carboxaldehyde
421	222	C_3-alkyl-9-fluorenone
431	222	methylanthraquinone/phenanthrenequinone
439	222	methylanthraquinone/phenanthrenequinone
454	218	hydroxypyrene/fluoranthene
462	218	hydroxypyrene/fluoranthene
474	236	C_4-alkyl-9-fluorenone
492	236	C_2-alkylanthraquinone
511	220	methylanthracene/phenanthrene-9-carboxaldehyde
549	256	unidentified (an oxy-PAH)
553	230	benz[*de*]anthracenone/benzofluorenone
567	230	benz[*de*]anthracenone/benzofluorenone
604	230	7*H*-benz[*de*]anthracen-7-one
633	278	dibutyl phthalate
648	258	benz[*a*]anthracenedione
663	244	hydroxychrysene/benz[*a*]anthracene/triphenylene
710	254	benzo[*cd*]pyrenone
717	254	benzo[*cd*]pyrenone
754	254	benzo[*cd*]pyrenone

Most compounds detected in the mutagenic subfractions C3, C4, and C5 of the diesel particulate extracts were oxy-PAH derivations. These compounds could conceivably be formed by oxidation of the corresponding parent PAHs during sample collection. Nitro-PAHs could be formed by reaction of nitrogen oxides with parent PAHs on the filter. Some evidence to this effect has been presented recently (53, 54). However, it appears likely that at least some oxy-PAHs are formed prior to collection on the filters. Since a wide variety of PAHs are frequently detected in airborne particulates collected usually by somewhat analogous method, it is less likely that the PAHs adsorbed to the diesel particulates will be extensively oxidized during the relatively short sample collection period. Carefully designed studies need to be performed to determine if any of the mutagenicity of diesel particulate extract samples is an artifact of sample collection procedure.

During the course of this investigation and since its completion in June 1981, several papers on the isolation of mutagenic fractions of diesel particulate extracts and characterization of the constitutents present in these fractions have been published (53-58). Schuetzle, et. al., (55) have characterized several PAHs and oxy-PAHs in two diesel particulate extract samples by low and high resolution GC/MS. This group has also characterized several nitro-PAHs including 1-nitropyrene in four extract samples by GC/MS, high resolution MS and MS/MS technique.

The mutagenicity of many oxy-PAH compounds detected in the mutagenic fractions of diesel particulate extract samples by us and others, is undetermined at this time. Several nitropyrenes have been shown to be direct-acting mutagens as determined by the Ames Salmonella assay. However, there is no evidence from this study at this time to suggest that mutagenicity of the diesel particulate extracts is primarily due to the nitro-PAHs. Various oxy-PAHs are likely to make a considerable contribution to the mutagenicity of the diesel particulate extracts. A few benzopyrene ketones have been reported to be direct-acting mutagens (59) as are oxidation products of pyrene and some hydroxy-PAHs(60). Additional information regarding mutagenicity of polycyclic carbonyl compounds is needed to assess possible mutagenic contributions of such compounds. Research should be directed to such studies, as well as to investigations on confirmed identification of constituents in mutagenic fractions of different extract samples from vehicles under real-world driving conditions.

In the time since the completion of chemical analysis work by Dr. Choudhury on this project, 10 in-use vehicle particulate extract samples have been examined by the chemical research group of Karasek and Sweetman, et. al. of the University of Waterloo (Ontario). A report on their work characterizing the PAHs in these 10 samples selected from the in-use vehicle portion of this project has been submitted to the Ontario Ministry of the Environment (61).

Samples were analyzed by GC and GC/MS after HPLC fractionation. 29 PAH's were quantified. 23 ketone, quinone, carboxaldehyde and nitro-PAH compounds were identified in the moderately polar fraction. Benzo(c)cinnoline and methyl-benzo(c) cinnoline were identified in the polar fractions. The few most abundant PAH's appeared to account for a significant portion of the mutagenicity (with activation). The highest nitro-pyrene concentration coincided with the greatest direct-acting mutagenicity but was not high enough to explain the activity. Benz(cd)pyrenone was tentatively identified in another sample with high direct-acting mutagenicity.

SECTION 9

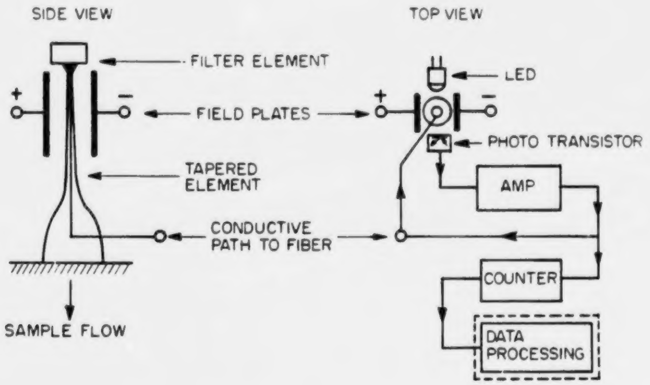
REAL TIME PARTICULATE MASS MONITORING

A portion of this project was directed toward the first time use of a tapered element oscillating microbalance (TEOM) for real-time diesel particulate mass monitoring. The full results of this application have been reported previously (62), and this section will only summarize the instrumentation and study results.

The TEOM is a hollow glass rod, fixed at a wide base, with a removable filter element attached to the narrow top, and oscillating in an electric field (Figure 9.1). The TEOM has been shown to behave as a harmonic oscillator (63) with a frequency dependence upon the mass collected by the filter element. If the TEOM is oscillating at frequency f_a at time = t_a and between time = t_a and time = t_b collects a quantity of mass, dm, the frequency of oscillation will be reduced to frequency f_b at time = t_b. The functional relationship is given by:

$$dm = K\left(f_b^{-2} - f_a^{-2}\right) ,$$

where K is a determinable calibration constant.



TEOM OPERATION

1. Electric field is set up between field plates.
2. Image of tapered element is projected on phototransistor
3. Oscillation of element initiated electrically or mechanically produces an AC voltage output from phototransistor.
4. AC voltage is amplified and applied to conductive path on element which maintains the oscillation due to interaction with field set up in Step 1
5. Frequency of oscillation and hence mass on filter element is determined by frequency counter

Figure 9.1. Schematic representation of TEOM instrumentation.

Thus the TEOM is shown to be a mass monitor. The TEOM, as tested (Figure 9.2), could respond to dilution tunnel concentrations as low as 1 to 2 mg/m^3 with a response time on the order of 8 to 15 seconds. Increased sensitivities could be achieved by longer response times or increasing the sample flow rate (2 to 2.5 l/min in this study). Longer response time compromises the objective of maximizing the real time capabilities of the instrument, while increasing the sample flow rate may introduce more signal noise. In this work, the instrument flow rate was actually reduced from the 5 l/min manufacturer design value as the loading of the filter during a driving cycle could become excessive. The resultant pressure drop across the filter could cause it to collapse, dramatically changing K in the mass frequency equation, thus invalidating a measurement.

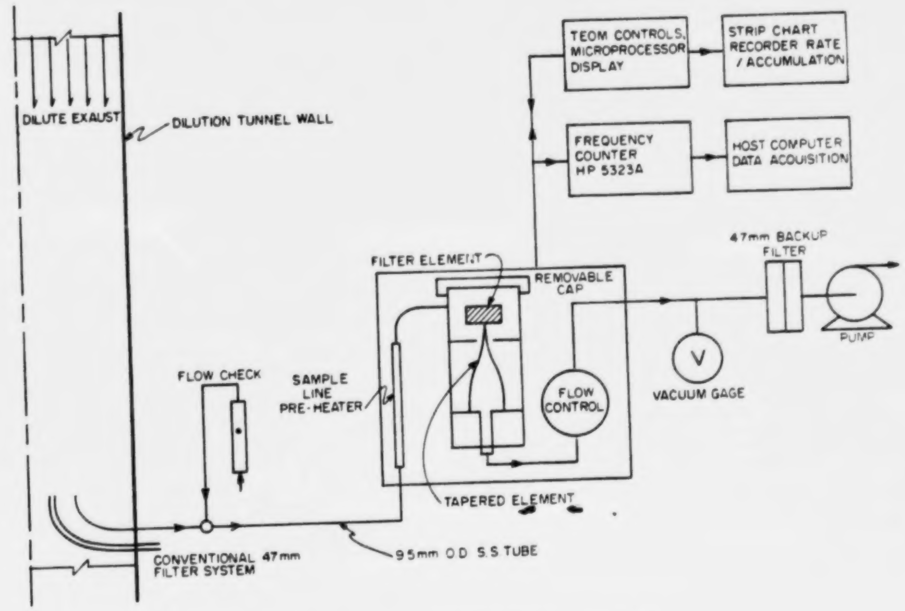

DILUTE EXAUST
DILUTION TUNNEL WALL
TEOM CONTROLS, MICROPROCESSOR DISPLAY
STRIP CHART RECORDER RATE / ACCUMULATION
FREQUENCY COUNTER HP 5323A
HOST COMPUTER DATA ACQUISITION
47mm BACKUP FILTER
FILTER ELEMENT
REMOVABLE CAP
PUMP
V
VACUUM GAGE
FLOW CONTROL
FLOW CHECK
SAMPLE LINE PRE-HEATER
TAPERED ELEMENT
CONVENTIONAL 47mm FILTER SYSTEM
9.5mm O.D. S.S TUBE

Figure 9.2. TEOM evaluation experimental design.

The TEOM signal was digitally filtered using a moving linear regression algorithm described in more detail elsewhere (62). As a consequence of this necessary signal filtering, the instrument, at the state of development for this study, was determined to have minimum response time frames on the order of 8 to 15 seconds.

Study vehicles (Car #1 and Car #5) were driven over the FTP Bag 3 and NYCC driving schedules using both standard 47 mm filter collection and TEOM monitoring for a total of 29 mass emission tests which are reported in Table 9.1. This table compares the total mass results determined by: (1) the TEOM using the fundamental mass-frequency equation; (2) a gravimetric determination of the mass collected by the TEOM filter; and (3) gravimetric determination of the standard procedure 47 mm filter mass. In the mean, the gravimetric determinations were within 10% of the TEOM mass determination; however, some large deviations were observed (tests 8 and 22). The TEOM filter is not designed for gravimetric analysis, and removal for weighing can result in the dislodging of particulate matter. Thus, filter handling may be the cause of extreme differences between the frequency and gravimetric determined masses.

Other errors may have been encountered as a result of the adsorption of water on the filter and particulate and differences in filter media. The TEOM filters were Ballston type CQ or CH material and the 47 mm filters were Pallflex type T60A20. The TEOM sample flow rate was 2 to 2.5 l/min while the 47 mm flow rate was 9 l/min. The 47 mm gravimetric values in Table 9.1 were adjusted to account for the difference in flows.

TABLE 9.1 COMPARISON OF TOTAL MASS EMISSION DETERMINATIONS BY TEOM AND STANDARD 47mm FILTER GRAVIMETRIC METHODS FOR PARTICULATES FROM DIESEL VEHICLES

Run #	1 TEOM Microprocessor Output mg	2 TEOM Gravimetric Filter Element mg	3 Dilution Tunnel 47 mm Filter mg*	Ratio $\frac{1}{2}$	Ratio $\frac{1}{3}$
1	.505	.539	.400	0.94	1.26
2	.352	.390	.399	0.90	0.88
3	.369	.374	.393	0.99	0.95
4	.384	.414	.419	0.93	0.82
5	.423	.456	.475	0.93	1.14
6	.354	.387	.368	0.91	0.96
7	.305	.289	.356	1.06	0.85
8	.383	.236	.416	1.62	0.92
9	.333	.296	.336	1.13	0.99
10	.327	.284	.325	1.15	1.01
11	.332	.284	.335	1.17	0.99
12	.303	.326	.327	0.93	0.93
13	.291	.259	.328	1.12	0.89
14	.279	.255	.324	1.09	0.86
15	.269	.261	.341	1.03	0.79
16	.309	.272	.321	1.14	0.96
17	.330	.301	.319	1.10	1.03
18	.311	.327	.302	0.95	1.03
19	.281	.274	.300	1.03	0.94
20	.343	.353	.356	0.97	0.96
21	.266	.293	.327	0.91	0.81
22	.297	.208	.324	1.43	0.92
23	.274	.273	.341	1.00	0.80
24	.253	.227	.342	1.11	0.74
25	.385	.347	.346	1.11	1.11
26	.430	.375	.380	1.15	1.13
27	.395	.333	.341	1.19	1.16
28	.576	.523	.542	1.10	1.06
29	.340	.348	.392	0.98	0.87
			Mean	1.07	0.96
			C.V. (%)	15%	13%

*Total collected mass, (mg), scaled to TEOM flow, weights determined immediately after run.

Figures 9.3-9.5 present the real time data obtained for Cars #1 and #5 over the NYCC and FTP Bag 3 driving schedules. The CVS flows were 9 m^3/min for Car #1 and 14 m^3/min for Car #5. Therefore, although the TEOM mass accumulation for each car over the FTP Bag 3 schedule was nearly the same, the mass emission from Car #5 was greater than for Car #1 (Figures 9.4 and 9.5).

Figures 9.6 and 9.7 present a three run test of driving cycle real time mass emission rate reproducibility using the TEOM. Variation in the actual vehicle emissions and the driver ability to reproduce a driving schedule were factors in addition to instrument variability which affect the overall reproducibility presented.

The TEOM frequency signal was digitally filtered using a 15 sec moving (one second units) linear regression algorithm. Applying the same filtering to the vehicle one second acceleration data for comparison to the TEOM mass rate data emphasized

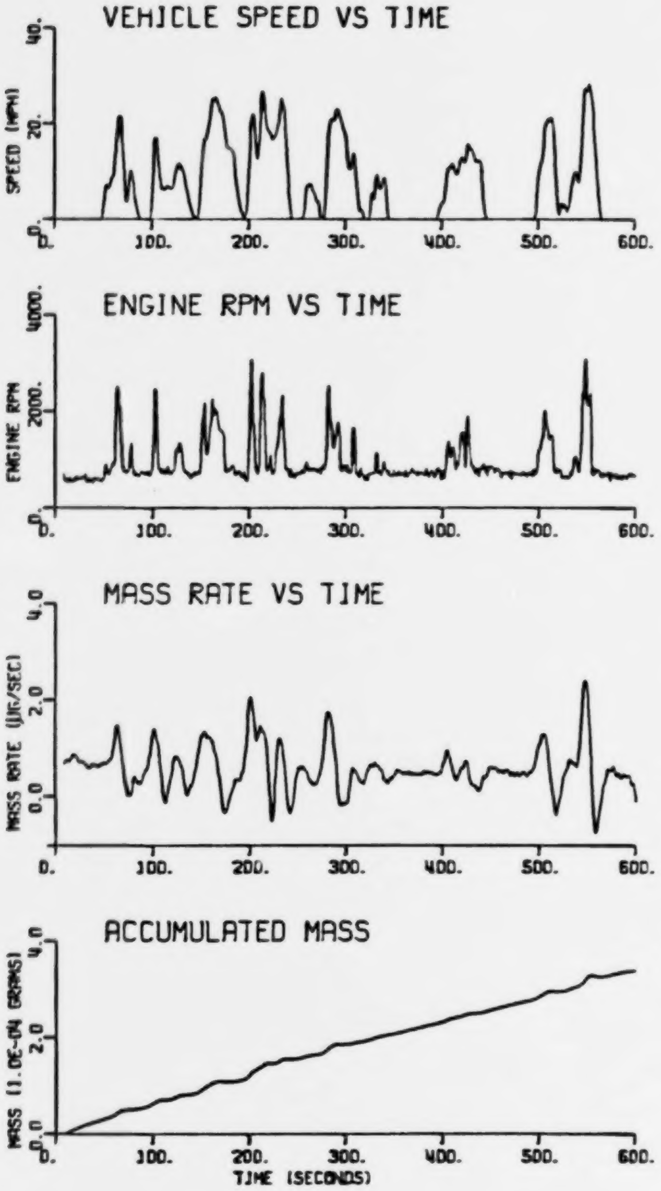


Figure 9.3. Vehicle speed, engine rpm, TEOM mass rate (μg/sec), and total TEOM accumulated mass vs. time for Oldsmobile 5.7 liter diesel driven over the NYCC schedule.

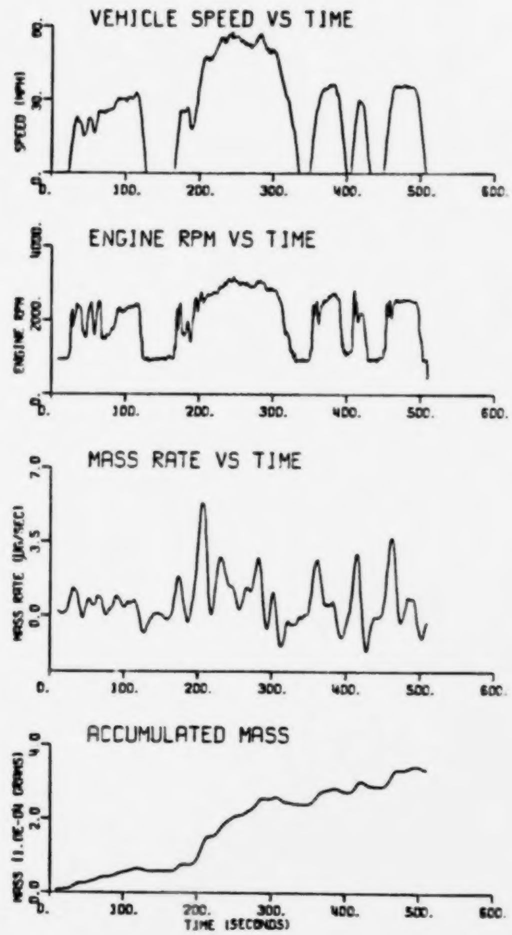


Figure 9.4. Vehicle speed, engine rpm, TEOM mass rate (μg/sec), and total TEOM accumulated mass vs. time for Oldsmobile 5.7 liter diesel driven over the FTP Bag 3 schedule.

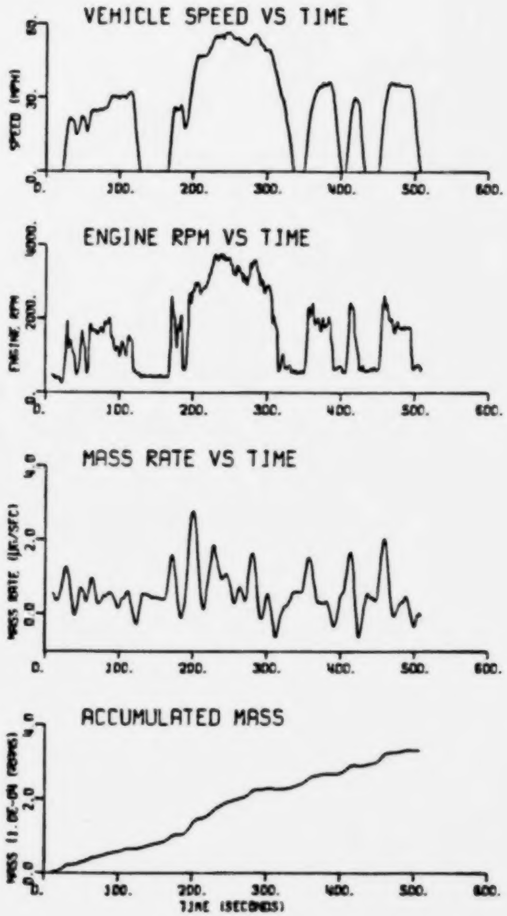


Figure 9.5. Vehicle speed, engine rpm, TEOM mass rate (μg/sec), and total TEOM accumulated mass vs. time for Volkswagen Rabbit 1.5 liter diesel driven over the FTP Bag 3 schedule.

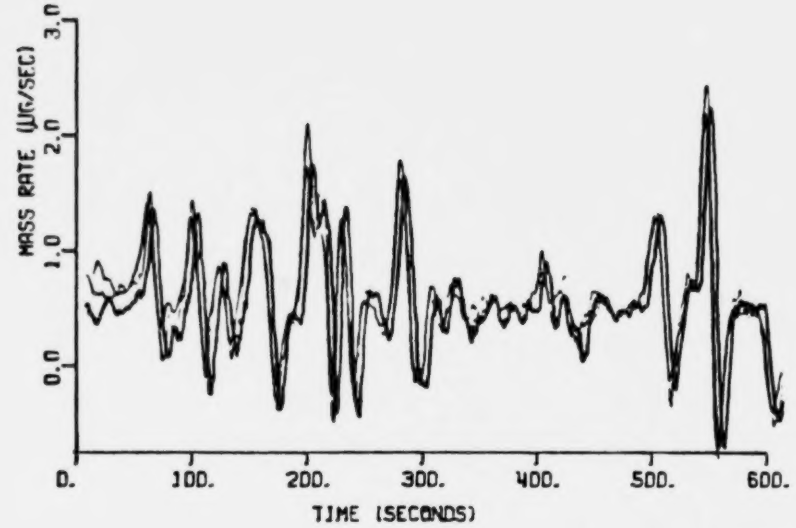


Figure 9.6. Reproducibility of TEOM mass rate (µg/sec) for three consecutive trials of the NYCC schedule by Car #5 (Oldsmobile 5.7 liter diesel).

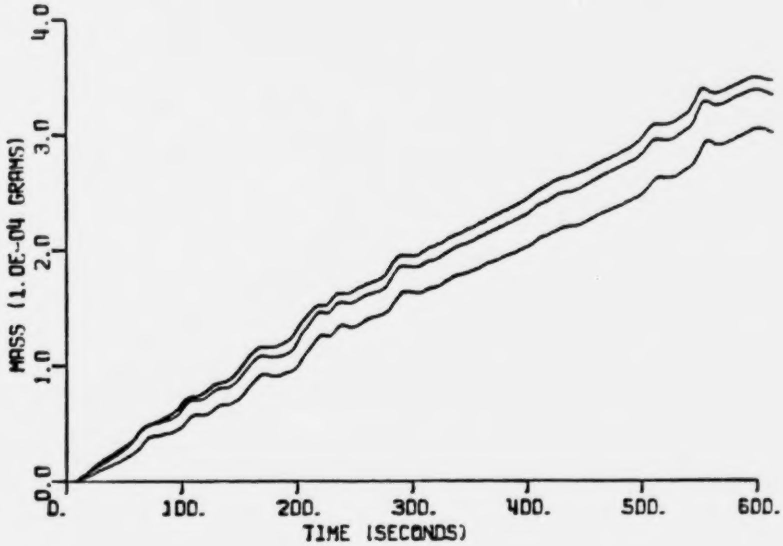


Figure 9.7. Reproducibility of TEOM mass accumulation (10^{-4} grams) for three consecutive trials of the NYCC schedule by Car #5 (Oldsmobile 5.7 liter diesel).

the strong relationship between vehicle acceleration and mass rate as shown in Figure 9.8. The negative mass rates which appear to be associated with periods of deceleration, are of particular interest. Although no experimental data concerning the source of this observation were obtained, it was hypothesized that the effect was caused by the desorption of water from the filter element and collected particulate matter during the drier and cleaner exhaust conditions of deceleration. It is considered probable that this same phenomenon also occurs in the standard particulate collection procedures but is unobserved as the gravimetric filter method is not a real time technique.

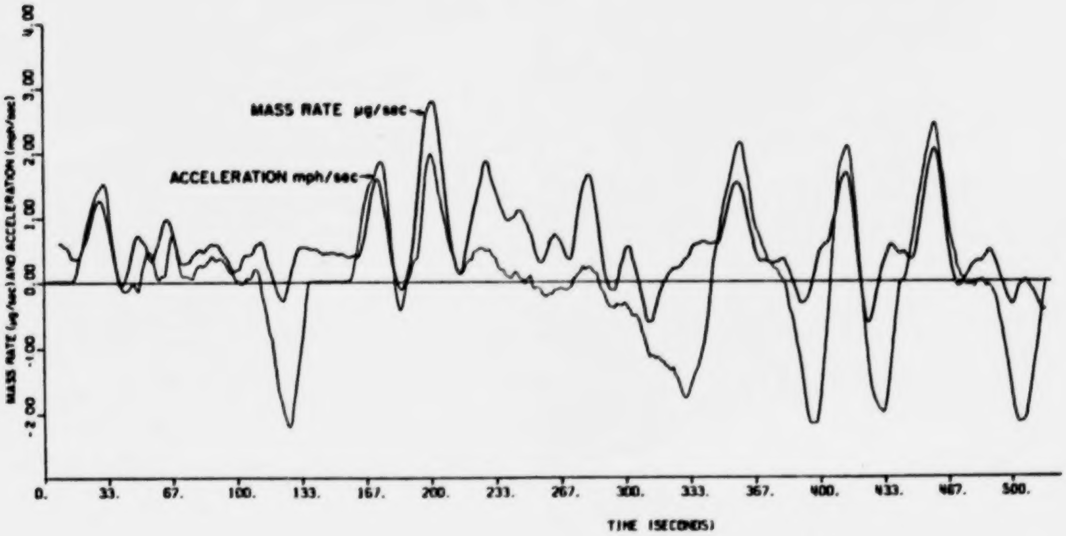


Figure 9.8 TEOM mass rate (ug/sec) and vehicle acceleration (mph/sec) for Car #5 (Oldsmobile 5.7 liter diesel) over the FTP Bag 3 schedule. (TEOM mass rate computed by least squares regression smoothing of TEOM frequencies using 15 second smoothing window; vehicle acceleration obtained by identical smoothing algorithm applied to one second average vehicle speeds.)

In a final test of the instrument, the inertial load of a vehicle was varied for three trials of the FTP Bag 3 schedule. The real time results in Figures 9.9 and 9.10 show that mass rate peak values were greater for higher inertial loading but that the total accumulation was signficantly greater only for inertial loading in excess of the 4000 lb inertial loading specified by the vehicle manufacturer.

This short study to evaluate the TEOM as a real time monitor for diesel particulate mass emissions concluded that the instrument, as tested, was capable of determining mass rates over time frames as short as eight seconds and total accumulations in good agreement, in general, with standard gravimetric filter procedures. The TEOM was considered to give reproducible results to the extent that TEOM results were within the range of variation considered reasonable for repetitive vehicle tests.

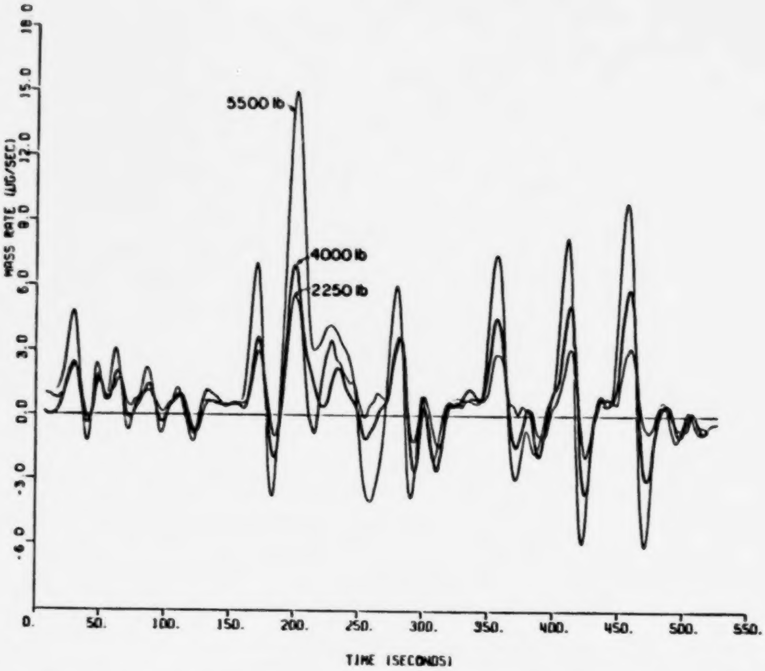


Figure 9.9 TEOM mass rate (ug/sec) vs. time at three dynamometer inertial weight settings for Car #5 (Oldsmobile 5.7 liter diesel) driven over the FTP Bag 3 schedule. (The manufacturer's specified inertial setting was 4000 lb.)

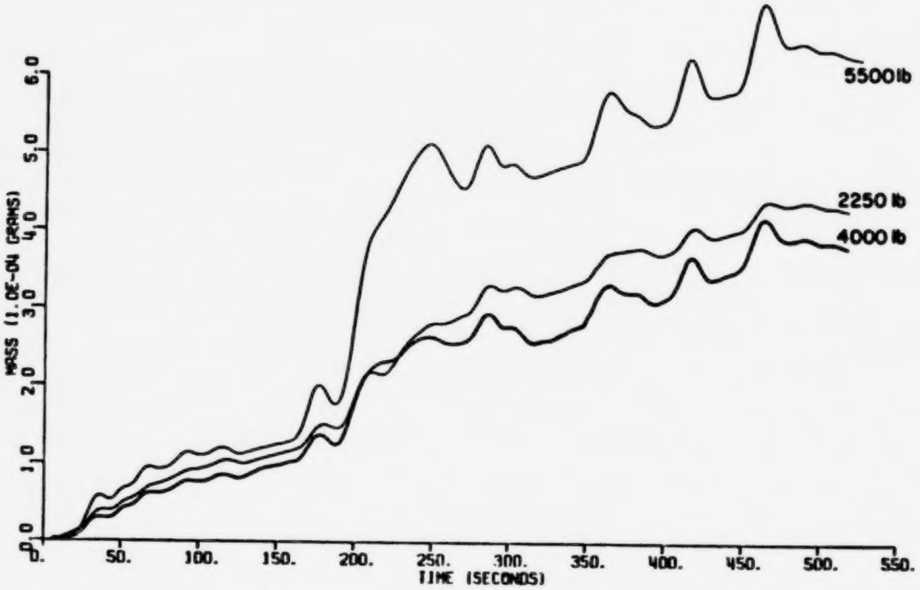


Figure 9.10 Accumulated TEOM mass (10^{-4} grams) vs. time at three dynamometer inertial weight settings for Car #5 (Oldsmobile 5.7 liter diesel) driven over the FTP Bag 3 schedule. (The manufacturer's specified inertial setting was 4000 lb.)

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APPENDIX A

VEHICLE AVERAGE EMISSION RESULTS

A-1 Particulate, Phase 1 (g/mi)
A-2 Particulate, Phase 3 (g/mi)
A-3 Residue, Phase 1 (g/mi)
A-4 Residue, Phase 3 (g/mi)
A-5 Extract, Phase 1 (g/mi)
A-6 Extract, Phase 3 (g/mi)
A-7 Extract, Phase 1 (%)
A-8 Extract, Phase 3 (%)
A-9 Non-Volatile Hydrocarbons, Phase 1, (% of Total HC)
A-10 Non-Volatile Hydrocarbons, Phase 3, (% of Total HC)
A-11 Total Hydrocarbons, Phase 1, (g/mi)
A-12 Total Hydrocarbons, Phase 3, (g/mi)
A-13 Carbon Monoxide, Phase 1, (g/mi)
A-14 Carbon Monoxide, Phase 3, (g/mi)
A-15 Nitrogen Oxides, Phase 1, (g/mi)
A-16 Nitrogen Oxides, Phase 3, (g/mi)
A-17 Fuel Economy, Phase 1, (MPG)
A-18 Fuel Economy, Phase 3, (MPG)
A-19 Revertants/μg Particulate, Phase 1
A-20 Revertants/μg Particulate, Phase 3
A-21 Revertants/μg Extract, Phase 1
A-22 Revertants/μg Extract, Phase 3
A-23 Revertants/mile, Phase 1
A-24 Revertants/mile, Phase 3

Table A-1:

PARTICULATE, G/MI, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	0.38	0.35	0.38	0.39	0.51	0.52	0.31	0.40
2	0.92	0.73	0.50	0.49	2.02	1.04	0.90	0.85
3	0.74	0.45	0.31	0.26	1.75	0.90	0.72	0.63
4	1.20	0.87	0.69	0.64	2.37	1.52	1.10	1.15
5	0.81	0.52	0.38	0.29	1.74	1.03	0.77	0.71
6	0.33	0.25	0.22	0.20	0.40	0.51	0.27	0.30
7	0.98	0.56	0.37	0.37	2.28	1.03	1.06	0.79
8	0.42	0.41	0.36	0.30	0.50	0.55	0.35	0.46
9	0.33	0.33	0.34	0.31	0.42	0.53	0.24	0.35
10	0.59	0.55	0.50	0.38	0.68	1.12	0.35	0.67
11	0.36	0.33	0.30	0.28	0.53	0.48	0.28	0.41
12	0.47	0.41	0.37	0.36	0.91	0.52	0.45	0.46
13	0.62	0.43	0.42	0.40	0.92	0.76	0.63	0.49
14	0.50	0.40	0.38	0.35	0.94	0.56	0.48	0.48
15	0.64	0.51	0.44	0.36	1.18	0.70	0.62	0.63
16	0.82	0.53	0.39	0.32	1.68	1.00	0.80	0.72
17	0.45	0.41	0.35	0.27	0.84	0.59	0.41	0.44
18	0.81	0.39	0.23	0.19	1.03	1.66	0.61	0.53
19	0.48	0.43	0.43	0.37	0.84	0.60	0.42	0.50
20	0.93	0.61	0.44	0.91	2.10	1.06	0.92	0.82
21	0.47	0.35	0.42	0.37	0.57	0.69	0.40	0.43

Table A-2:

PARTICULATE, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	0.45	0.34	0.35	0.36	0.47	0.77	0.35	0.41
2	0.98	0.71	0.55	0.51	2.02	1.14	0.94	0.91
3	0.77	0.48	0.35	0.29	1.81	0.89	0.77	0.68
4	1.25	0.91	0.76	0.64	2.49	1.56	1.13	1.22
5	0.82	0.54	0.39	0.33	1.72	1.00	0.79	0.75
6	0.38	0.24	0.21	0.19	0.39	0.41	0.38	0.35
7	0.82	0.55	0.41	0.36	1.82	0.97	0.85	0.75
8	0.40	0.44	0.35	0.31	0.44	0.53	0.31	0.48
9	0.33	0.34	0.33	0.31	0.42	0.50	0.24	0.37
10	0.76	0.54	0.42	0.31	0.80	1.41	0.55	0.66
11	0.36	0.33	0.29	0.28	0.48	0.49	0.25	0.44
12	0.53	0.41	0.37	0.37	0.91	0.60	0.53	0.48
13	0.61	0.47	0.46	0.46	0.99	0.69	0.61	0.55
14	0.55	0.39	0.35	0.32	0.89	0.61	0.57	0.48
15	0.62	0.50	0.42	0.37	0.95	0.75	0.59	0.58
16	0.81	0.53	0.57	0.33	1.66	0.94	0.78	0.77
17	0.51	0.34	0.34	0.29	0.94	0.59	0.49	0.48
18	0.81	0.41	0.27	0.23	1.08	1.29	0.74	0.57
19	0.52	0.46	0.39	0.32	0.72	0.82	0.39	0.53
20	0.33	0.36	0.43	0.32	0.56	0.57	0.26	0.26

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Table A-3: RESIDUE. G/MI, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC
1	0.32	0.29	0.32	0.33	0.41
2	0.59	0.39	0.23	0.20	1.24
3	0.60	0.33	0.22	0.17	1.42
4	0.98	0.67	0.52	0.46	1.89
5	0.65	0.39	0.27	0.20	1.37
6	0.28	0.20	0.18	0.17	0.29
7	0.72	0.37	0.23	0.19	1.58
8	0.34	0.33	0.28	0.24	0.39
9	0.26	0.25	0.28	0.25	0.28
10	0.45	0.39	0.33	0.20	0.46
11	0.24	0.21	0.19	0.18	0.25
12	0.34	0.29	0.27	0.25	0.70
13	0.56	0.38	0.38	0.35	0.83
14	0.44	0.34	0.33	0.28	0.80
15	0.44	0.35	0.33	0.27	0.74
16	0.69	0.41	0.29	0.22	1.37
17	0.20	0.15	0.11	0.08	0.30
18	0.41	0.14	0.09	0.06	0.31
19	0.43	0.39	0.40	0.33	0.74
20	0.73	0.44	0.28	0.52	1.45
21	0.33	0.13	0.12	0.07	0.46

Table A-4: RESIDUE, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC
1	0.37	0.29	0.29	0.30	0.37
2	0.59	0.35	0.22	0.18	1.26
3	0.60	0.34	0.22	0.16	1.38
4	0.95	0.64	0.50	0.40	1.67
5	0.63	0.38	0.26	0.21	1.34
6	0.31	0.19	0.15	0.16	0.29
7	0.59	0.36	0.25	0.19	1.21
8	0.33	0.35	0.28	0.24	0.32
9	0.26	0.26	0.25	0.25	0.29
10	0.58	0.37	0.24	0.16	0.55
11	0.25	0.22	0.19	0.19	0.23
12	0.40	0.30	0.27	0.27	0.68
13	0.55	0.42	0.41	0.40	0.89
14	0.49	0.34	0.31	0.27	0.76
15	0.46	0.38	0.34	0.29	0.62
16	0.67	0.42	0.42	0.23	1.32
17	0.22	0.12	0.10	0.09	0.30
18	0.32	0.15	0.10	0.07	0.39
19	0.48	0.41	0.35	0.29	0.63
20	0.23	0.14	0.12	0.07	0.43

Table A-5: EXTRACT, G/MI, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC
1	0.06	0.06	0.05	0.06	0.10
2	0.33	0.34	0.27	0.29	0.78
3	0.14	0.12	0.09	0.09	0.33
4	0.22	0.19	0.17	0.18	0.49
5	0.15	0.12	0.11	0.09	0.38
6	0.05	0.05	0.04	0.03	0.08
7	0.26	0.19	0.14	0.17	0.70
8	0.08	0.08	0.07	0.06	0.11
9	0.07	0.08	0.06	0.06	0.14
10	0.15	0.16	0.18	0.18	0.23
11	0.11	0.12	0.11	0.10	0.28
12	0.12	0.11	0.10	0.11	0.21
13	0.06	0.05	0.05	0.05	0.10
14	0.06	0.05	0.05	0.06	0.13
15	0.20	0.15	0.11	0.10	0.44
16	0.13	0.11	0.10	0.10	0.32
17	0.26	0.27	0.24	0.19	0.54
18	0.45	0.25	0.14	0.13	0.72
19	0.05	0.04	0.04	0.03	0.10
20	0.20	0.16	0.16	0.38	0.65
21	0.14	0.22	0.30	0.30	0.11

Table A-6: EXTRACT, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC
1	0.08	0.06	0.05	0.05	0.10
2	0.38	0.36	0.32	0.33	0.76
3	0.17	0.14	0.12	0.13	0.42
4	0.29	0.27	0.25	0.24	0.82
5	0.19	0.15	0.13	0.12	0.38
6	0.07	0.05	0.05	0.03	0.09
7	0.23	0.19	0.16	0.17	0.62
8	0.07	0.09	0.07	0.07	0.12
9	0.07	0.08	0.07	0.06	0.13
10	0.17	0.17	0.17	0.15	0.25
11	0.11	0.12	0.10	0.09	0.25
12	0.13	0.11	0.11	0.10	0.23
13	0.06	0.05	0.05	0.05	0.10
14	0.07	0.05	0.04	0.05	0.13
15	0.16	0.12	0.09	0.08	0.33
16	0.14	0.11	0.15	0.10	0.34
17	0.29	0.24	0.24	0.21	0.63
18	0.49	0.26	0.17	0.16	0.70
19	0.04	0.05	0.03	0.03	0.09
20	0.10	0.21	0.30	0.25	0.13

Table A-7: PERCENT EXTRACT, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC
1	16.0	16.4	14.4	15.6	18.9
2	34.0	44.1	51.4	55.7	38.7
3	18.6	26.0	29.4	34.7	18.3
4	17.7	21.8	24.1	27.1	20.3
5	19.0	23.7	27.4	29.6	21.5
6	16.1	19.5	19.4	16.4	22.7
7	26.0	33.0	37.5	46.2	30.7
8	19.1	20.1	20.3	21.9	21.9
9	20.4	22.7	19.3	19.5	33.8
10	24.7	29.2	35.4	47.9	33.1
11	33.1	37.8	36.3	35.3	53.6
12	26.0	28.3	27.3	29.6	23.1
13	9.7	10.8	10.9	11.8	10.6
14	12.2	13.4	12.2	17.2	14.2
15	30.5	30.0	24.8	26.5	37.6
16	15.9	21.5	25.3	29.7	18.8
17	56.2	64.4	67.9	68.4	64.2
18	55.9	63.5	61.4	66.2	70.5
19	9.9	10.6	9.2	9.1	12.5
20	21.5	27.0	36.0	42.2	31.0
21	30.5	62.7	71.3	80.4	20.1

Table A-8: PERCENT EXTRACT, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC
1	17.9	16.7	15.7	15.5	21.3
2	37.1	47.2	53.4	58.7	37.5
3	22.4	29.2	34.0	43.3	23.5
4	21.7	27.5	30.3	31.8	24.8
5	22.9	28.5	32.0	34.5	22.1
6	17.4	20.4	24.5	17.1	23.3
7	27.1	33.1	36.6	42.5	33.7
8	17.6	20.7	20.0	22.4	27.9
9	20.1	24.0	21.9	20.0	30.0
10	23.2	31.7	41.7	48.0	30.9
11	32.0	34.9	34.3	31.7	52.2
12	24.9	27.4	28.1	27.3	22.5
13	9.9	10.2	10.0	11.1	10.3
14	11.7	12.8	11.9	14.7	14.8
15	24.9	24.4	20.6	20.2	34.6
16	17.0	20.6	24.6	29.5	20.3
17	56.6	63.0	69.0	67.5	67.2
18	58.6	62.1	63.6	68.9	66.0
19	8.6	10.6	8.5	8.6	12.7
20	30.8	60.1	71.0	77.0	24.0

Table A-9:

NON-VOLITILE HYDROCARBONS, PHASE 1, (% of Total HC)

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	18.9	21.1	19.7	18.7	20.9	17.8	19.5	21.8
2	40.5	63.1	64.1	81.3	36.9	32.8	42.7	48.8
3	28.6	39.8	39.0	42.0	24.8	26.3	30.9	31.8
4	38.6	59.9	67.3	90.6	38.8	31.5	38.9	48.9
5	29.6	40.1	44.2	49.4	35.1	25.4	30.0	35.3
6	22.3	23.9	22.2	33.0	53.9	23.8	23.8	19.6
7	37.2	43.9	37.0	54.8	40.2	31.3	39.7	37.6
8	23.2	25.0	35.6	33.0	20.2	21.9	25.0	22.7
9	31.7	40.0	27.7	49.2	51.7	32.9	29.9	33.2
10	38.8	52.4	60.7	83.6	58.1	59.1	26.4	45.4
11	35.7	49.4	62.1	76.8	25.8	41.1	30.9	40.7
12	34.4	49.9	47.3	57.2	37.2	22.9	38.0	47.3
13	31.4	44.0	53.1	66.4	129.7	32.0	30.2	36.5
14	27.0	37.1	43.1	64.1	29.3	21.9	26.4	36.9
15	40.6	41.0	35.7	39.7	48.8	44.6	39.7	40.0
16	28.0	42.7	48.6	48.5	35.4	24.9	27.1	35.2
17	35.8	57.0	70.7	88.7	20.7	40.1	33.1	38.4
18	20.3	28.0	37.8	44.3	16.9	27.5	15.1	24.1
19	33.1	54.7	52.7	56.1	46.4	33.3	27.8	47.2
20	26.8	38.7	43.8	98.4	35.9	19.5	29.5	32.5
21	19.6	11.8	12.9	12.1	29.9	18.6	29.2	12.9

Table A-10:

NON-VOLATILE HYDROCARBONS, PHASE 3, (% of Total HC)

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	27.0	23.4	26.2	24.3	24.4	30.1	25.4	26.6
2	43.0	61.5	64.8	79.1	34.0	38.7	42.4	49.4
3	31.1	42.7	43.4	56.4	31.3	26.0	32.1	35.8
4	40.4	63.7	74.5	67.2	45.4	36.7	37.3	53.6
5	31.9	42.5	44.1	52.9	30.5	27.8	31.7	38.5
6	31.3	22.0	30.6	29.2	35.5	23.7	39.7	23.1
7	32.0	43.2	45.1	53.9	28.3	25.6	33.6	35.0
8	21.5	28.0	35.0	32.7	22.7	19.9	21.2	22.2
9	32.0	41.0	37.6	47.7	87.3	31.3	32.5	32.5
10	45.0	67.2	83.9	94.0	46.8	44.3	44.4	48.4
11	30.7	41.3	55.8	57.1	23.8	37.4	23.2	35.4
12	29.5	41.1	46.6	53.4	28.4	22.7	30.9	36.0
13	29.2	38.8	47.2	55.3	48.7	23.6	29.6	36.8
14	22.0	28.0	34.2	34.8	24.0	19.1	21.9	26.7
15	36.0	36.8	33.5	38.5	48.5	41.6	34.8	34.3
16	27.6	34.5	55.0	46.4	28.5	25.7	25.7	35.1
17	34.5	47.9	70.0	76.5	22.2	33.1	34.3	36.1
18	19.3	24.9	41.4	50.0	17.2	24.7	15.5	25.2
19	26.1	45.0	45.3	42.7	32.2	30.6	19.9	35.9
20	12.2	12.8	12.5	9.6	34.1	16.2	18.6	6.0

Table A-11:

GASEOUS HYDROCARBONS, G/MI, PHASE 1

CAR	FTP	CFDS	HFET	SOC	NYCC	BAG1	BAG2	BAG3
1	0.33	0.28	0.29	0.37	0.47	0.48	0.29	0.29
2	0.71	0.50	0.41	0.55	2.13	0.99	0.72	0.60
3	0.48	0.29	0.24	0.24	1.31	0.67	0.47	0.37
4	0.55	0.31	0.25	0.28	1.25	0.85	0.50	0.41
5	0.52	0.31	0.24	0.24	1.08	0.76	0.50	0.38
6	0.24	0.22	0.20	0.13	0.12	0.36	0.18	0.25
7	0.69	0.42	0.37	0.45	1.73	0.86	0.70	0.55
8	0.34	0.33	0.21	0.22	0.55	0.48	0.26	0.40
9	0.22	0.19	0.21	0.19	0.31	0.33	0.17	0.22
10	0.36	0.31	0.29	0.21	0.39	0.47	0.30	0.37
11	0.32	0.25	0.17	0.15	1.11	0.37	0.31	0.32
12	0.35	0.23	0.21	0.22	0.56	0.58	0.31	0.25
13	0.19	0.11	0.09	0.08	0.12	0.25	0.20	0.13
14	0.23	0.14	0.11	0.12	0.45	0.33	0.22	0.16
15	0.49	0.39	0.33	0.30	0.88	0.50	0.48	0.50
16	0.47	0.27	0.21	0.22	0.93	0.67	0.47	0.32
17	0.74	0.47	0.33	0.27	2.61	0.85	0.74	0.64
18	2.18	0.90	0.40	0.36	4.63	3.26	2.27	1.20
19	0.14	0.08	0.08	0.06	0.23	0.18	0.15	0.11
20	0.74	0.42	0.36	0.39	1.81	1.18	0.67	0.54
21	0.73	1.87	2.32	2.47	0.38	1.14	0.42	1.02

Table A-12:

GASEOUS HYDROCARBONS, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	SOC	NYCC	BAG1	BAG2	BAG3
1	0.32	0.26	0.22	0.25	0.41	0.51	0.25	0.29
2	0.85	0.55	0.46	0.64	2.28	1.08	0.83	0.69
3	0.55	0.33	0.27	0.29	1.36	0.76	0.54	0.43
4	0.66	0.40	0.32	0.44	1.52	0.90	0.65	0.49
5	0.59	0.36	0.28	0.29	1.25	0.82	0.58	0.45
6	0.24	0.23	0.20	0.14	0.26	0.32	0.20	0.26
7	0.77	0.41	0.33	0.44	2.21	1.02	0.66	0.58
8	0.33	0.34	0.21	0.29	0.55	0.45	0.26	0.39
9	0.21	0.20	0.20	0.19	0.19	0.32	0.16	0.23
10	0.39	0.26	0.21	0.16	0.53	0.75	0.28	0.31
11	0.36	0.28	0.18	0.19	1.05	0.42	0.35	0.36
12	0.45	0.28	0.23	0.22	0.80	0.65	0.43	0.33
13	0.21	0.12	0.10	0.11	0.25	0.29	0.21	0.15
14	0.30	0.18	0.12	0.15	0.55	0.40	0.30	0.22
15	0.43	0.33	0.27	0.25	0.67	0.46	0.42	0.43
16	0.51	0.31	0.25	0.29	1.27	0.64	0.53	0.38
17	0.88	0.50	0.35	0.33	2.90	1.03	0.88	0.77
18	2.53	1.13	0.51	0.45	4.26	3.26	2.85	1.37
19	0.17	0.10	0.07	0.07	0.28	0.22	0.17	0.13
20	0.82	1.67	2.43	2.60	0.39	1.09	0.44	1.36

Table A-13:

CARBON MONOXIDE. G/MI, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	1.17	1.05	1.12	1.42	2.07	1.45	1.04	1.21
2	1.74	1.20	0.98	0.98	4.22	1.87	1.87	1.50
3	1.48	0.99	0.83	0.82	3.68	1.63	1.54	1.26
4	1.97	1.27	1.06	1.07	4.42	2.12	2.08	1.65
5	1.61	1.02	0.91	0.93	3.54	1.76	1.69	1.35
6	1.04	0.74	0.69	0.60	1.44	1.22	1.00	0.97
7	1.71	1.11	0.93	0.90	4.03	1.77	1.83	1.44
8	1.26	1.16	0.94	0.98	1.92	1.58	1.04	1.44
9	1.05	0.81	0.83	0.79	1.62	1.82	0.82	0.90
10	1.97	1.60	1.29	1.09	2.63	2.34	1.80	2.03
11	1.16	0.82	0.66	0.65	3.23	1.27	1.15	1.07
12	1.21	0.90	0.86	0.77	2.09	1.54	1.18	1.01
13	1.19	0.84	0.77	0.81	1.72	1.30	1.20	0.98
14	1.27	1.02	0.95	1.00	2.43	1.53	1.26	1.10
15	1.85	1.43	1.23	1.15	3.49	2.11	1.75	1.82
16	1.57	1.01	0.87	0.83	3.32	1.76	1.64	1.27
17	1.55	0.96	0.81	0.78	4.06	1.61	1.74	1.13
18	2.67	1.40	0.97	0.86	6.00	3.16	2.83	1.99
19	0.97	0.74	0.71	0.64	1.72	1.13	0.95	0.90
20	1.75	1.11	0.97	0.92	4.47	2.01	1.81	1.43
21	1.81	1.56	1.46	1.04	1.88	2.21	1.43	2.24

Table A-14:

CARBON MONOXIDE, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	1.18	1.00	0.94	1.15	2.01	1.47	1.09	1.15
2	1.83	1.20	1.02	1.02	4.47	1.92	1.93	1.55
3	1.53	1.02	0.87	0.84	3.73	1.68	1.58	1.32
4	1.97	1.32	1.07	1.14	4.67	2.10	2.07	1.69
5	1.64	1.09	0.92	0.94	3.51	1.79	1.72	1.37
6	1.05	0.76	0.65	0.61	1.79	1.20	1.04	0.95
7	1.62	1.09	0.91	0.94	3.99	1.48	1.78	1.40
8	1.27	1.17	0.88	1.05	1.87	1.55	1.06	1.44
9	0.92	0.81	0.75	0.75	1.66	1.19	0.81	0.91
10	1.92	1.43	1.10	0.99	3.45	2.43	1.75	1.88
11	1.14	0.87	0.67	0.60	2.99	1.28	1.11	1.10
12	1.30	0.93	0.87	0.80	2.78	1.53	1.33	1.08
13	1.23	0.91	0.89	0.89	2.00	1.37	1.27	1.06
14	1.47	1.03	0.94	0.99	2.55	1.67	1.50	1.25
15	1.67	1.29	1.10	1.01	2.98	1.98	1.55	1.66
16	1.56	1.02	0.87	0.83	3.60	1.67	1.65	1.32
17	1.59	0.93	0.85	0.79	4.31	1.63	1.74	1.26
18	2.63	1.51	1.03	0.93	6.41	2.89	2.88	1.94
19	0.99	0.73	0.68	0.62	1.76	1.14	0.99	0.90
20	1.79	1.72	1.56	1.10	1.97	2.19	1.45	2.12

Table A-15:

NITROGEN OXIDES, G/MI, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	0.90	0.81	0.81	0.82	1.26	0.92	0.90	0.89
2	1.80	1.47	1.43	1.38	3.19	1.70	1.86	1.72
3	1.57	1.29	1.29	1.21	2.41	1.52	1.62	1.50
4	2.03	1.62	1.62	1.63	3.47	1.91	2.12	1.97
5	1.89	1.39	1.41	1.34	3.00	1.74	2.02	1.77
6	0.89	0.62	0.57	0.56	1.67	0.90	0.96	0.75
7	1.81	1.36	1.27	1.25	2.82	1.64	1.95	1.66
8	0.95	0.85	0.89	0.96	1.45	0.97	0.94	0.95
9	1.20	1.09	1.13	1.23	1.64	1.19	1.23	1.17
10	3.30	3.14	3.39	3.44	4.04	3.66	3.07	3.44
11	0.93	0.76	0.75	0.76	1.45	0.96	0.95	0.89
12	1.29	1.13	1.06	1.08	1.93	1.36	1.27	1.28
13	1.76	1.48	1.45	1.33	2.51	1.85	1.77	1.72
14	1.39	1.27	1.27	1.26	2.17	1.41	1.42	1.35
15	1.90	1.43	1.40	1.41	2.79	1.81	2.05	1.69
16	1.61	1.19	1.11	1.11	2.83	1.56	1.71	1.46
17	1.03	0.84	0.79	0.76	1.51	1.10	1.07	0.91
18	1.10	0.79	0.74	0.77	2.17	0.99	1.21	0.97
19	1.70	1.55	1.55	1.36	2.54	1.77	1.65	1.74
20	1.54	1.22	1.22	1.25	2.39	1.51	1.57	1.51
21	1.79	1.50	1.45	1.48	2.98	1.71	1.87	1.71

Table A-16:

NITROGEN OXIDES, G/MI, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	0.93	0.82	0.85	0.85	1.35	0.99	0.91	0.92
2	1.73	1.43	1.41	1.35	2.97	1.62	1.81	1.68
3	1.53	1.25	1.25	1.20	2.44	1.47	1.58	1.50
4	1.99	1.64	1.59	1.59	3.42	1.85	2.07	1.96
5	1.82	1.45	1.41	1.36	2.84	1.69	1.92	1.72
6	0.84	0.59	0.55	0.56	1.63	0.82	0.90	0.74
7	1.74	1.34	1.28	1.21	2.62	1.60	1.88	1.61
8	0.96	0.87	0.91	0.96	1.37	0.97	0.96	0.96
9	1.21	1.12	1.15	1.30	1.83	1.18	1.24	1.19
10	3.15	3.01	3.19	3.07	4.42	3.44	2.94	3.33
11	0.88	0.76	0.78	0.82	1.44	0.90	0.87	0.88
12	1.32	1.11	1.09	1.12	2.05	1.38	1.30	1.30
13	1.81	1.49	1.48	1.31	2.63	1.91	1.80	1.76
14	1.50	1.26	1.26	1.23	2.23	1.56	1.51	1.43
15	2.05	1.49	1.45	1.45	2.93	1.99	2.20	1.79
16	1.60	1.21	1.14	1.12	2.89	1.45	1.72	1.49
17	1.02	0.79	0.80	0.77	1.60	1.04	1.05	0.95
18	1.10	0.81	0.69	0.80	3.20	1.01	1.20	0.98
19	1.71	1.53	1.52	1.32	2.37	1.95	1.61	1.72
20	1.73	1.42	1.42	1.42	2.87	1.74	1.77	1.63

Table A-17:

FUEL ECONOMY, MPG, PHASE 1

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	42.9	53.4	55.7	57.9	29.9	38.5	44.1	44.7
2	20.0	27.1	30.1	32.0	10.6	18.3	19.7	21.8
3	20.7	28.0	30.4	32.7	11.6	18.8	20.5	22.7
4	19.4	27.1	29.4	30.8	10.3	18.2	18.8	21.7
5	20.7	30.3	31.3	33.2	11.4	19.0	20.3	23.2
6	41.7	55.7	58.9	64.0	28.6	37.0	41.7	46.0
7	18.7	26.7	30.2	32.4	10.9	17.9	18.1	20.8
8	42.6	52.9	54.0	54.4	28.3	39.1	43.3	44.4
9	43.8	54.8	56.1	60.0	30.8	39.8	44.2	46.6
10	18.5	24.9	26.0	27.2	13.7	15.7	19.2	19.9
11	41.7	53.4	54.9	57.3	26.7	38.5	41.7	44.6
12	27.6	34.9	36.4	37.5	18.6	25.1	27.8	29.4
13	22.9	28.7	30.4	31.6	17.1	20.0	23.5	24.3
14	27.8	32.4	34.6	35.6	18.5	25.2	28.1	29.3
15	27.2	34.7	36.8	38.7	19.1	25.6	27.1	29.0
16	19.3	26.9	29.3	31.4	10.9	17.0	19.5	21.3
17	27.4	34.2	35.7	37.1	18.9	24.5	27.3	30.7
18	20.2	28.8	32.0	34.1	11.5	17.9	20.1	22.4
19	23.3	28.9	30.3	31.6	15.5	20.5	24.0	24.4
20	19.2	26.3	28.7	30.8	11.2	17.0	19.6	20.4
21	23.1	28.3	29.9	32.3	15.9	20.3	23.7	24.6

Table A-18:

FUEL ECONOMY, MPG, PHASE 3

CAR	FTP	CFDS	HFET	50C	NYCC	BAG1	BAG2	BAG3
1	41.7	52.0	55.1	58.5	29.3	36.7	42.6	44.4
2	19.9	27.2	29.8	32.0	10.9	18.5	19.6	21.8
3	20.7	28.2	30.8	33.6	12.0	19.3	20.3	22.8
4	19.4	26.4	29.3	30.3	10.2	18.2	19.0	21.1
5	20.9	28.1	31.2	33.1	11.8	19.5	20.6	22.9
6	43.7	57.1	61.3	65.3	29.6	40.5	43.6	46.7
7	19.0	26.8	29.9	32.5	11.0	17.8	18.1	21.0
8	43.2	52.7	54.7	56.6	31.0	39.5	43.9	45.0
9	44.0	53.6	58.4	59.0	29.6	39.8	44.5	46.6
10	19.7	25.8	27.4	29.1	12.3	17.1	20.2	21.1
11	43.0	52.5	56.6	57.8	27.5	39.2	43.8	44.9
12	27.0	34.9	36.6	37.5	17.4	24.7	27.1	29.1
13	23.2	29.4	30.2	33.0	16.7	20.2	23.9	24.4
14	25.6	31.8	33.8	34.8	18.0	22.8	25.8	27.5
15	26.5	34.5	36.7	39.5	19.3	24.7	26.3	28.5
16	19.1	26.4	28.9	30.8	10.3	18.0	18.9	20.6
17	26.7	35.9	35.0	36.6	18.3	24.1	26.9	28.5
18	19.9	28.3	31.5	34.0	11.3	18.0	19.8	21.9
19	23.1	28.3	30.3	32.4	15.8	20.4	23.8	24.3
20	24.5	29.0	29.8	31.3	16.2	20.9	25.9	25.2

Table A-19: REVERTANTS PER UG PARTICULATE, PHASE 1

CAR	FTP	CFDS	HFET	SOC	NYCC
1	1.2	1.5	1.6	1.5	1.3
2	0.8	0.9	0.9	0.7	0.3
3	0.9	0.8	0.7	0.7	0.4
4	0.5	0.4	0.3	0.3	0.4
5	0.6	0.5	0.6	0.6	0.2
6	2.4	3.3	3.3	1.7	1.1
7	0.8	0.9	1.0	1.3	0.4
8	1.3	1.6	1.1	0.7	0.2
9	1.0	1.2	1.2	0.9	0.6
10	0.9	0.9	0.6	0.3	0.4
11	1.7	1.4	1.0	1.2	1.3
12	0.5	0.5	0.3	0.1	0.4
13	0.5	0.5	0.5	0.3	0.1
14	0.8	0.9	0.6	0.7	0.4
15	1.2	1.4	1.7	1.7	0.9
16	0.8	0.8	0.9	0.9	0.5
17	0.9	0.9	0.4	0.4	0.3
18	0.8	0.9	0.9	1.0	0.3
19	0.6	0.9	0.6	0.8	0.3
20	1.0	0.8	1.0	1.5	0.9
21	1.9	2.3	2.4	1.4	0.5

Table A-20: REVERTANTS PER UG PARTICULATE, PHASE3

CAR	FTP	CFDS	HFET	SOC	NYCC
1	3.0	2.3	2.3	1.7	1.6
2	0.7	0.8	0.7	0.9	0.3
3	0.8	0.7	0.8	0.9	0.5
4	0.5	0.4	0.3	0.3	0.3
5	0.6	0.6	0.6	0.6	0.2
6	2.2	3.3	2.3	1.6	1.9
7	0.8	0.7	0.7	0.8	0.6
8	2.5	2.7	2.4	1.0	0.2
9	1.4	1.3	1.3	1.1	0.6
10	0.9	1.0	0.7	0.5	0.6
11	1.6	1.8	1.1	1.0	1.8
12	0.5	0.4	0.3	0.3	0.4
13	0.4	0.4	0.3	0.2	0.1
14	0.9	1.0	0.7	0.8	0.5
15	1.4	1.8	1.8	1.2	1.0
16	1.0	1.0	1.0	1.0	0.6
17	0.3	0.7	0.5	0.5	0.2
18	1.8	1.1	1.1	1.1	0.4
19	0.9	1.6	0.8	0.8	0.3
20	2.5	2.2	2.2	1.7	0.4

Table A-21: REVERTANTS PER UG EXTRACT, PHASE 1

CAR	FTP	CFDS	HFET	SOC	NYCC
1	7.9	9.7	12.3	9.7	7.4
2	2.9	2.4	2.2	1.6	0.9
3	4.9	3.5	2.9	2.2	2.4
4	3.4	2.3	1.1	1.3	1.8
5	3.7	2.5	2.6	2.2	1.1
6	16.8	17.6	18.6	11.4	8.6
7	3.5	3.4	3.3	3.8	1.2
8	6.7	7.5	5.5	3.0	0.9
9	6.7	6.9	8.0	6.1	1.8
10	3.4	3.3	1.7	0.6	1.3
11	5.2	3.9	3.1	3.4	2.4
12	1.9	2.1	1.1	0.5	1.6
13	5.3	5.1	5.4	2.3	1.4
14	5.9	6.6	4.6	3.5	2.6
15	4.3	4.6	7.1	7.1	2.4
16	4.9	3.9	3.5	3.2	2.9
17	1.6	1.4	0.5	0.6	0.4
18	1.6	1.4	1.4	1.6	0.4
19	5.5	7.7	5.9	8.2	2.2
20	4.5	3.1	2.8	3.5	2.8
21	6.2	3.7	3.4	1.7	2.5

Table A-22: REVERTANTS PER UG EXTRACT, PHASE 3

CAR	FTP	CFDS	HFET	SOC	NYCC
1	18.1	13.9	14.9	11.0	7.6
2	2.8	2.5	1.9	2.1	0.9
3	3.9	2.7	2.7	2.0	2.4
4	2.7	1.8	1.4	1.3	1.6
5	2.6	2.3	1.9	1.8	1.0
6	14.6	17.7	10.3	10.2	20.2
7	3.8	2.8	2.6	2.3	1.8
8	15.4	14.0	14.1	4.4	0.7
9	9.7	8.2	8.0	8.4	2.3
10	3.8	3.3	1.6	0.9	1.8
11	5.0	5.3	3.3	3.3	3.2
12	2.0	1.4	1.0	1.1	2.0
13	4.6	4.3	3.6	2.1	1.3
14	7.9	8.4	6.4	5.3	3.8
15	6.0	8.3	8.7	6.3	2.8
16	5.3	4.6	3.9	3.3	2.8
17	0.6	1.2	0.8	0.8	0.4
18	3.0	1.9	1.8	1.7	0.6
19	11.6	18.2	10.0	8.9	2.3
20	8.0	3.6	3.1	2.2	1.8

Table A-23: REVERTANTS PER MILE x 10^5, PHASE 1

CAR	FTP	CFDS	HFET	SOC	NYCC
1	4.3	5.5	6.6	6.6	6.9
2	6.6	5.8	3.6	3.1	6.9
3	6.7	3.9	2.1	2.0	8.9
4	6.5	3.7	1.8	2.2	9.6
5	4.5	2.5	2.0	1.6	4.2
6	8.3	8.2	7.7	3.5	4.1
7	7.4	4.9	3.7	4.4	10.5
8	5.6	6.7	3.8	2.0	1.2
9	3.2	3.9	4.2	2.9	2.4
10	5.8	5.3	3.1	1.1	2.9
11	6.0	4.8	3.3	3.3	6.7
12	2.3	2.2	1.2	0.5	3.0
13	3.4	2.3	2.3	1.0	1.6
14	3.8	3.8	2.5	2.3	3.7
15	7.8	7.2	7.6	6.3	11.0
16	6.3	4.2	3.5	2.9	9.1
17	4.2	3.8	1.3	1.1	2.1
18	6.7	3.2	1.8	1.7	2.8
19	2.8	3.6	2.2	2.8	2.4
20	9.0	5.1	4.4	13.4	18.2
21	8.8	8.2	10.2	5.1	2.9

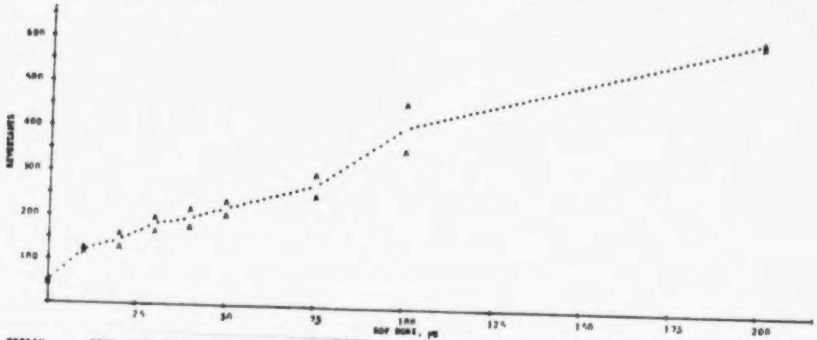
Table A-24: REVERTANTS PER MILE x 10^5, PHASE 3

CAR	FTP	CFDS	HFET	SOC	NYCC
1	13.9	8.2	8.4	6.4	7.7
2	5.4	4.4	3.1	3.1	6.8
3	5.4	3.3	2.7	2.6	9.9
4	5.6	3.4	2.0	1.5	
5	4.6	3.3	2.2	1.9	3.8
6	7.8	8.3	4.2	3.3	7.1
7	6.2	3.6	2.5	2.2	9.6
8	10.4	11.8	7.6	2.6	1.0
9	4.9	4.6	4.2	3.5	2.5
10	6.7	5.6	2.8	1.4	4.4
11	5.0	6.2	3.1	2.8	8.1
12	2.7	1.6	1.0	1.1	
13	2.7	1.9	1.6	1.0	1.3
14	5.2	4.1	2.5	2.5	4.7
15	9.2	9.7	7.7	4.8	9.8
16	7.7	5.1	6.6	3.1	9.5
17	1.7	2.7	1.6	1.2	2.2
18	16.4	4.7	2.7	2.1	4.7
19	4.8	8.0	2.9	2.3	1.9
20	8.1	7.7	9.4	5.5	2.4

APPENDIX B   TYPICAL DOSE RESPONSE CURVES FOR TA98(-) AMES TESTS

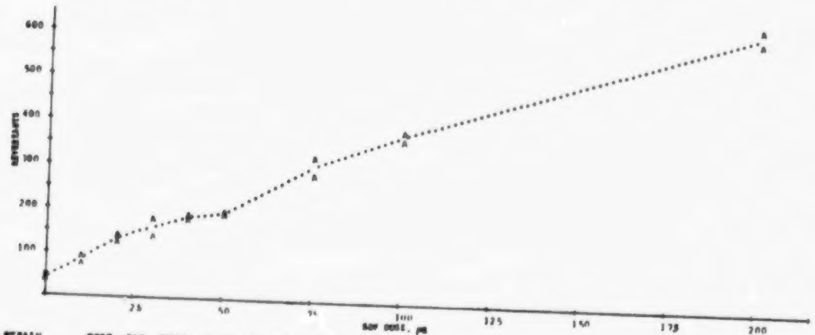
```
STRAIN       TEST  CAR  PHASE  CYCLE  FILTER  BOTTLE  RUN
TA98 -        7     2     3      7     541     261    910

      DOSE      COLONIES
BACKGROUND        46        46        HIGH DOSE   SLOPE   INTERCEPT  R-SQUARE  REV/100µgms
        10       113       124
        20       126       156           200      2.72     82.62      0.96       355
        30       162       191           100      3.13     68.29      0.91       382
        40       171       211            75      2.76     77.24      0.89       353
        50       200       231            50      3.16     69.40      0.90       386
        75       266       296            40      3.53     64.60      0.87       418
       100       350       436            30      4.17     58.20      0.89       475
       200       601       612
```



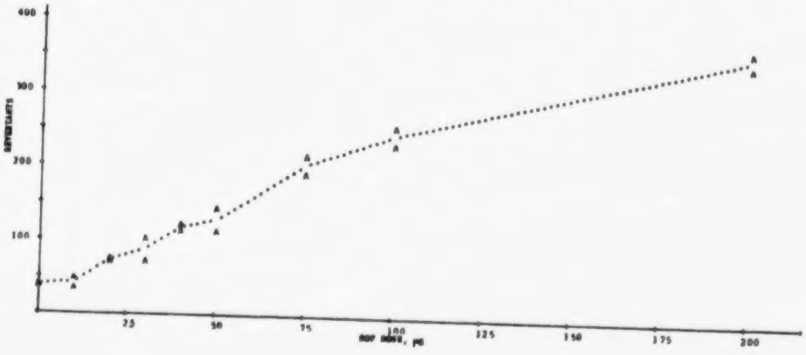
```
STRAIN       TEST  CAR  PHASE  CYCLE  FILTER  BOTTLE  RUN
TA98 -        8     6     3     173    586     271    924

      DOSE      COLONIES
BACKGROUND        37        37        HIGH DOSE   SLOPE   INTERCEPT  R-SQUARE  REV/100µgms
        10        72        88
        20       136       121           200      2.87     61.05      0.98       348
        30       135       174           100      3.27     47.60      0.98       374
        40       176       185            75      3.29     46.93      0.96       376
        50       192       197            50      3.13     50.52      0.92       361
        75       281       320            40      3.59     44.00      0.96       403
       100       363       352            30      4.03     39.45      0.93       441
       200       601       612
```



```
STRAIN       TEST  CAR  PHASE  CYCLE  FILTER  BOTTLE  RUN
TA98 -       30     2     3     133    1082    518    930

      DOSE      COLONIES
BACKGROUND        37        37        HIGH DOSE   SLOPE   INTERCEPT  R-SQUARE  REV/100µgms
        10        34        47
        20        74        70           200      1.68     44.20      0.95       212
        30        71       101           100      2.20     36.44      0.97       246
        40       121       112            75      2.25     25.27      0.95       250
        50       143       112            50      1.90     30.31      0.90       229
        75       191       215            40      2.05     29.50      0.90       234
       100       231       256            30      1.79     32.10      0.80       211
       200       345       365
```



APPENDIX C

VEHICLE TEST FUEL ANALYSES

Table C-1: Test Fuel Analysis.

Data for as-received test fuel for all tests are listed by test number. Average values and statistics are presented for all as-received fuels. "AEL" denotes Project Reference Fuel Analysis. Columns are from left to right: Test number; API gravity at 60°F by ASTM D287-67; specific gravity at 60°F by ASTM D287-67; Heating Value (BTU/lb) by ASTM D240-64; Ash Content (%) by ASTM D482-74; Sulfur (S) by ASTM D1552-64; Carbon (C) and Hydrogen (H) by ASTM D-3178-73 reapproved 1979 - modified (oxidant purified air instead of oxygen); Nitrogen (N) by ASTM D3179-73 reapproved 1979; Oxygen (O) by ASTM "Ultimate Analysis Method" D3176-74 reapproved 1979 (mathematical differencing method); Percent Saturates (% SAT), % Olefins (% OLEF), and % Aromatics (% AROM) by ASTM D1319; and calculated Cetane Index (CETANE INDEX) by ASTM D976-66 reapproved 1971. After test 34 ASTM D1319 analyses not available from EPA/RTP.

Table C-2: Test Fuel Distillation Profile by ASTM D86-67.

Data for as-received test fuel for all tests are listed by test number. Average values and statistics are presented for all as-received fuels. "AEL" denotes Project Reference Fuel analysis. Columns are from left to right: Test number, initial boiling point, 5% recovery, 10% recovery, 20% recovery, 30% recovery, 40% recovery, 50% recovery, 60% recovery, 70% recovery, 80% recovery, 90% recovery, 95% recovery, End Point, % recovery, % residue, % loss.

TABLE C-1 ANALYSIS OF TEST FUELS*

TEST	API 60° GRAVITY	SPECIFIC GRAVITY	BTU/LB	BTU/GAL	% ASH	%S	%C	%H	%N	%O	% SAT.	%OLEFINS	% AROM.	CETANE INDEX
1	34.4	0.8529	19428	137978	0.0005	0.13	86.64	12.99	0.04	0.20	65.5	0.6	33.9	45.2
2	34.4	0.8529	19360	137494	0.0005	0.22	86.34	12.72	0.04	0.68	63.4	0.4	36.2	43.2
3	35.5	0.8473	19469	137354	0.0005	0.10	86.11	13.34	0.04	0.41	65.8	0.6	33.6	44.1
4	35.7	0.8463	19279	0	0.0010	0.09	86.32	12.86	0.04	0.69	64.1	0.6	35.3	44.2
5	34.7	0.8514	19421	137675	0.0005	0.13	86.39	12.51	0.03	0.94	62.9	1.3	35.8	47.2
6	35.8	0.8458	19348	136249	0.0005	0.13	85.92	12.84	0.04	1.07	64.4	0.5	35.1	45.2
7	37.0	0.8398	19469	136127	0.0005	0.09	86.42	13.22	0.04	0.23	65.2	1.0	33.8	44.7
8	33.6	0.8571	19325	137903	0.0005	0.14	86.39	12.61	0.04	0.82	69.0	1.3	29.7	42.3
9	37.5	0.8373	19579	136485	0.0005	0.30	86.34	13.19	0.04	0.13	67.7	0.6	31.7	44.7
10	35.7	0.8463	19530	137628	0.0005	0.21	87.24	12.33	0.04	0.28	72.4	1.9	25.7	48.7
11	37.1	0.8393	19562	136699	0.0005	0.26	85.20	13.56	0.06	0.92	75.3	1.3	23.4	45.6
12	38.2	0.8338	19521	135534	0.0005	0.16	86.39	13.25	0.04	0.16	59.7	1.9	38.4	51.2
13	35.2	0.8488	19512	137911	0.0005	0.31	86.17	13.34	0.06	0.12	61.0	0.8	38.2	48.4
14	37.5	0.8373	19562	136367	0.0005	0.29	86.31	13.21	0.06	0.13	58.4	0.9	40.7	45.5
15	36.7	0.8413	19571	137095	0.0030	0.21	85.90	13.00	0.04	0.85	62.7	0.4	36.9	50.0
16	36.6	0.8418	19418	136101	0.0030	0.18	86.14	13.04	0.06	0.58	62.0	1.2	36.8	46.7
17	35.9	0.8453	19513	137332	0.0005	0.11	86.68	12.95	0.01	0.25	61.5	0.2	38.3	44.3
18	36.0	0.8448	19449	136804	0.0005	0.18	86.28	12.87	0.01	0.66	61.7	0.6	37.7	46.6
19	35.7	0.8463	19804	139559	0.0005	0.16	86.53	12.94	0.03	0.34	60.9	0.8	38.3	45.6
20	35.5	0.8473	19372	136669	0.0005	0.19	87.24	12.27	0.04	0.26	62.9	0.6	36.5	47.5
21	36.4	0.8428	19745	138551	0.0005	0.13	86.96	12.76	0.01	0.15	62.3	0.7	37.0	46.8
22	36.3	0.8433	19418	136334	0.0005	0.25	85.95	12.58	0.04	1.12	67.9	0.4	31.7	48.5
23	36.3	0.8433	19780	138875	0.0005	0.11	87.02	12.30	0.03	0.54	68.2	0.8	31.0	45.9
24	35.4	0.8478	19730	139274	0.0005	0.18	87.66	11.72	0.03	0.41	66.4	2.7	30.9	44.6
25	35.5	0.8473	19402	136981	0.0005	0.34	83.70	12.98	0.04	2.88	62.5	0.4	37.1	47.2
26	36.1	0.8443	19449	136726	0.0005	0.18	87.19	11.06	0.04	1.53	63.6	1.0	35.4	46.0
27	35.7	0.8463	19429	136916	0.0005	0.34	85.56	12.62	0.04	1.00	60.1	1.0	38.9	46.9
28	34.9	0.8504	19722	139651	0.0005	0.29	86.19	12.58	0.03	0.91	59.6	1.0	39.4	50.1
29	35.7	0.8463	19743	139129	0.0005	0.24	87.16	11.72	0.04	0.84	59.5	0.5	40.0	45.5
30	35.8	0.8458	19696	138699	0.0005	0.11	87.34	12.28	0.03	0.23	60.9	0.4	38.7	46.0
31	35.8	0.8458	19336	136164	0.0005	0.11	87.36	11.75	0.03	0.75	64.0	1.0	35.0	44.9
32	35.1	0.8493	19617	138731	0.0005	0.10	87.48	11.35	0.04	1.03	61.4	0.5	38.1	45.2
33	35.5	0.8473	19739	139259	0.0005	0.10	86.87	12.09	0.04	0.90	59.0	0.4	40.6	46.7
34	38.2	0.8338	19865	137923	0.0050	0.10	86.67	13.14	0.03	0.06	61.9	1.0	37.1	56.4
35	35.8	0.8458	19455	137002	0.0005	0.15	86.67	12.76	0.01	0.41	0.0	0.0	0.0	48.6
36	36.0	0.8448	19459	136875	0.0005	0.15	86.46	13.34	0.03	0.02	0.0	0.0	0.0	47.1
37	37.1	0.8393	19493	136217	0.0005	0.26	86.11	13.32	0.01	0.30	0.0	0.0	0.0	46.2
38	42.5	0.8132	19705	133423	0.0005	0.03	85.96	13.87	0.01	0.13	0.0	0.0	0.0	49.7
39	34.3	0.8534	19241	136726	0.0005	0.20	86.16	12.96	0.03	0.65	0.0	0.0	0.0	43.6
40	37.6	0.8368	19683	137131	0.0005	0.13	86.21	13.23	0.01	0.42	0.0	0.0	0.0	46.5
41	38.1	0.8343	19669	136641	0.0005	0.20	86.28	13.36	0.04	0.12	0.0	0.0	0.0	50.0
42	42.0	0.8156	19427	131909	0.0005	0.21	86.44	13.31	0.03	0.00	0.0	0.0	0.0	52.7
43	41.9	0.8160	19786	134426	0.0005	0.07	85.26	14.08	0.07	0.52	0.0	0.0	0.0	49.9
44	37.7	0.8363	19520	135918	0.0005	0.16	85.59	13.23	0.10	0.92	0.0	0.0	0.0	48.6
45	38.1	0.8343	19494	135425	0.0050	0.22	86.20	13.28	0.10	0.20	0.0	0.0	0.0	47.6
46	36.1	0.8443	19481	136591	0.0005	0.07	86.13	13.59	0.10	0.11	0.0	0.0	0.0	51.2
47	38.0	0.8348	19542	135836	0.0005	0.15	85.74	13.36	0.03	0.72	0.0	0.0	0.0	48.8
48	36.3	0.8433	19502	136924	0.0005	0.01	86.26	13.12	0.03	0.59	0.0	0.0	0.0	45.4
49	36.2	0.8438	19486	136909	0.0005	0.22	86.16	12.98	0.04	0.60	0.0	0.0	0.0	46.4
50	34.9	0.8504	19476	137910	0.0005	0.19	86.34	12.94	0.06	0.47	0.0	0.0	0.0	45.6
51	35.0	0.8499	19429	137480	0.0005	0.15	86.47	12.87	0.03	0.48	0.0	0.0	0.0	46.3
52	36.3	0.8433	19506	136952	0.0005	0.15	85.99	13.20	0.04	0.62	0.0	0.0	0.0	47.9
53	37.9	0.8353	19598	136304	0.0005	0.14	86.26	13.45	0.03	0.12	0.0	0.0	0.0	50.4
54	34.8	0.8509	19375	137212	0.0005	0.19	86.67	12.89	0.04	0.21	0.0	0.0	0.0	45.2
55	34.4	0.8529	19162	136089	0.0005	0.16	86.62	13.02	0.04	0.16	0.0	0.0	0.0	45.2
56	33.9	0.8555	19337	137737	0.0005	0.11	86.49	12.62	0.03	0.75	0.0	0.0	0.0	44.5
57	36.5	0.8423	19543	137055	0.0005	0.17	85.94	13.40	0.01	0.48	0.0	0.0	0.0	49.2
58	37.9	0.8353	19552	135984	0.0005	0.16	86.48	13.21	0.03	0.12	0.0	0.0	0.0	53.2
59	36.1	0.8443	19480	136944	0.0005	0.22	86.28	12.95	0.03	0.52	0.0	0.0	0.0	48.4
60	37.9	0.8353	19539	135894	0.0005	0.13	86.42	13.33	0.03	0.09	0.0	0.0	0.0	52.2
61	37.9	0.8353	19673	136826	0.0005	0.12	86.22	13.46	0.03	0.17	0.0	0.0	0.0	53.2
62	36.8	0.8408	19442	136094	0.0005	0.15	86.39	13.26	0.03	0.17	0.0	0.0	0.0	50.2
63	35.6	0.8468	19565	137953	0.0005	0.19	86.44	13.04	0.03	0.30	0.0	0.0	0.0	48.0
64	35.6	0.8468	19486	137396	0.0005	0.19	86.40	13.18	0.03	0.20	0.0	0.0	0.0	47.7
65	35.6	0.8468	19524	137664	0.0005	0.26	86.35	13.19	0.03	0.17	0.0	0.0	0.0	48.0
66	35.6	0.8468	19515	137600	0.0020	0.17	86.55	13.12	0.01	0.15	0.0	0.0	0.0	51.4
67	35.5	0.8473	19507	137622	0.0005	0.38	86.41	13.00	0.03	0.18	0.0	0.0	0.0	46.8
68	34.2	0.8540	19403	137955	0.0005	0.24	86.56	12.88	0.03	0.29	0.0	0.0	0.0	43.5
69	35.8	0.8458	19508	137375	0.0005	0.33	86.53	12.72	0.03	0.39	0.0	0.0	0.0	47.5
70	36.0	0.8448	19470	136952	0.0050	0.12	86.53	13.21	0.03	0.11	0.0	0.0	0.0	46.3
71	36.1	0.8443	19520	137226	0.0040	0.19	86.52	13.21	0.03	0.05	0.0	0.0	0.0	45.5
72	35.8	0.8458	19492	137263	0.0005	0.12	86.13	13.53	0.03	0.19	0.0	0.0	0.0	46.5
73	39.9	0.8256	19712	135500	0.0005	0.11	85.02	13.30	0.03	1.54	0.0	0.0	0.0	51.1
74	36.5	0.8423	19485	136648	0.0005	0.25	86.02	13.03	0.04	0.66	0.0	0.0	0.0	46.6
75	36.7	0.8413	19347	135715	0.0005	0.32	85.59	13.14	0.04	0.91	0.0	0.0	0.0	46.4
76	41.0	0.8203	19731	134763	0.0005	0.09	85.06	13.81	0.03	1.01	0.0	0.0	0.0	48.4
77	40.5	0.8227	19680	134808	0.0005	0.07	86.09	13.69	0.03	0.12	0.0	0.0	0.0	49.9
78	38.0	0.8348	19567	136010	0.0005	0.09	86.00	13.38	0.03	0.50	0.0	0.0	0.0	45.7
79	37.3	0.8383	19455	135796	0.0005	0.23	85.86	13.15	0.04	0.72	0.0	0.0	0.0	46.0
80	36.7	0.8413	19444	136205	0.0005	0.23	86.53	13.18	0.03	0.03	0.0	0.0	0.0	44.7
AVG	36.5	0.8423	19520	136898	0.0008	0.18	86.31	12.98	0.04	0.50	63.6	0.9	35.5	47.2
SD	1.8	0.0087	137	1283	0.0010	0.08	0.58	0.53	0.02	0.44	3.8	0.5	4.0	2.6
CV	4.8	1.0355	0.7	0.9	126.4	43.08	0.68	4.07	48.72	88.54	5.9	60.3	11.2	5.6
AEL	36.2	0.8438	19458	136717	0.0005	0.14	86.33	13.00	0.03	0.47	67.1	0.3	32.6	45.5

* Tests 1 to 80 are fuels used for Phase 1 only.
AEL designates the control fuel used in Phase 1 and Phase 3.

TABLE C-2: Test Fuel Distillation Profile by ASTM D86-67.

TEST	BOIL PT.	5 %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	95 %	END PT.	% REC.	% RES.	% LOSS
1	260	368	414	448	469	485	504	522	541	565	594	618	619	96.9	3.0	0.1
2	244	366	409	440	459	464	491	510	530	555	589	606	610	96.6	3.3	0.1
3	283	368	397	423	445	463	483	501	523	539	585	607	607	96.0	3.9	0.1
4	279	370	397	424	446	464	481	500	520	545	581	610	615	96.1	3.7	0.2
5	272	355	396	437	470	494	513	530	549	571	601	627	627	96.1	2.9	1.0
6	283	362	384	428	448	467	486	506	527	544	594	624	628	96.7	2.4	0.9
7	295	366	390	418	436	452	468	488	506	532	570	601	607	97.1	2.8	0.1
8	291	395	422	450	464	478	496	511	532	558	594	622	630	97.6	2.3	0.1
9	233	291	361	407	425	443	462	484	509	538	582	619	630	97.2	2.7	0.1
10	332	398	423	451	472	490	509	528	550	578	616	649	668	97.6	2.0	0.4
11	348	382	399	418	435	454	472	492	514	541	582	616	651	99.0	1.0	0.0
12	356	388	403	420	436	451	468	484	502	526	569	609	644	98.0	1.7	0.3
13	376	414	433	455	476	495	514	534	555	577	608	634	656	98.6	1.2	0.2
14	350	0	392	416	433	450	467	486	510	538	576	610	645	98.2	1.8	0.0
15	358	402	420	448	465	483	504	521	546	573	609	642	666	98.1	1.9	0.0
16	365	399	414	434	450	469	485	503	522	549	589	624	653	98.4	1.5	0.1
17	366	400	416	435	449	464	479	495	515	539	574	604	641	99.0	1.0	0.0
18	358	399	415	436	456	472	489	507	526	555	593	628	650	98.4	1.5	0.1
19	374	406	420	440	456	472	490	508	526	552	590	618	650	96.0	1.8	0.2
20	378	412	430	450	468	486	504	524	544	570	608	636	664	98.0	1.5	0.5
21	364	398	414	436	452	470	488	506	528	556	598	630	660	97.8	1.3	0.9
22	357	385	412	442	462	481	500	520	542	570	608	0	646	95.5	4.5	0.0
23	334	386	412	434	451	468	484	506	525	551	592	0	638	96.0	4.0	0.0
24	383	406	421	437	457	473	487	504	523	550	588	0	653	98.0	2.0	0.0
25	368	390	416	444	464	486	502	522	544	574	608	0	649	96.5	3.5	0.0
26	381	405	421	439	455	471	487	504	525	550	586	0	653	98.5	1.5	0.0
27	370	394	414	441	460	480	496	519	541	569	607	0	649	96.5	3.5	0.0
28	381	410	437	478	495	507	529	549	572	603	622	0	658	98.0	1.5	0.0
29	354	392	417	439	457	472	489	507	527	553	594	0	628	96.0	4.0	0.0
30	350	394	420	442	460	476	491	507	530	557	590	0	641	98.0	2.0	0.0
31	381	406	421	439	455	469	484	502	522	550	586	0	648	98.0	2.0	0.0
32	378	406	426	442	460	476	495	509	531	558	590	0	651	98.0	2.0	0.0
33	364	392	418	444	463	482	499	517	537	559	596	0	638	97.5	2.5	0.0
34	370	400	428	458	480	500	524	542	565	591	625	0	654	96.5	3.5	0.0
35	376	411	429	452	470	489	507	526	547	572	607	0	654	97.4	2.5	0.1
36	365	394	412	436	455	477	495	513	536	561	603	0	0	97.2	2.6	0.2
37	358	389	418	429	444	460	476	496	518	546	592	0	640	97.4	2.4	0.2
38	338	359	375	390	406	420	432	444	460	480	512	0	570	87.5	2.5	0.0
39	352	389	412	438	456	477	495	513	536	560	597	0	645	97.5	2.5	0.0
40	354	386	405	424	440	456	471	489	510	537	581	0	630	97.5	2.5	0.0
41	328	384	406	430	450	472	486	506	530	558	598	0	640	97.0	3.0	0.0
42	120	172	248	370	406	435	454	472	498	526	575	0	642	97.4	2.5	0.1
43	341	370	387	402	416	428	440	452	467	487	518	0	600	98.5	1.5	0.0
44	363	389	407	429	446	466	483	504	526	555	593	0	656	98.6	1.4	0.0
45	165	320	370	410	0	0	472	500	526	557	606	0	656	96.0	4.0	0.0
46	354	400	430	458	480	500	520	540	564	590	629	0	674	97.0	3.0	0.0
47	350	379	397	420	440	459	480	500	525	556	602	638	656	97.6	2.1	0.3
48	348	374	350	420	441	460	481	502	526	556	597	0	650	98.0	1.8	0.2
49	350	383	399	426	447	467	488	510	534	563	601	634	654	97.2	1.9	0.9
50	354	391	413	442	463	481	500	519	540	566	603	637	654	97.3	1.7	1.0
51	363	398	418	445	466	484	503	522	544	568	605	639	655	97.4	1.8	0.8
52	368	392	411	438	458	476	496	515	538	568	611	644	650	98.0	0.6	1.4
53	357	393	411	434	453	472	491	519	534	562	604	641	654	97.1	1.5	1.4
54	375	406	425	447	465	482	499	518	536	567	592	631	650	97.9	1.3	0.8
55	338	384	410	444	463	484	504	524	547	573	608	640	657	97.9	1.5	0.6
56	284	366	400	438	462	486	506	528	550	580	618	654	656	97.0	1.5	1.5
57	358	400	424	448	466	484	502	522	544	570	610	0	632	95.2	2.8	2.0
58	366	382	418	444	470	488	508	530	552	580	622	650	650	96.2	2.5	1.3
59	362	404	420	444	464	482	502	520	544	574	616	642	662	97.5	1.5	1.0
60	356	390	412	440	462	482	502	522	546	578	620	656	658	96.5	2.5	1.0
61	365	404	422	448	470	490	508	530	522	582	624	0	665	95.5	2.0	2.5
62	372	406	424	450	468	488	504	522	540	562	598	638	646	97.0	2.0	1.0
63	366	406	424	450	470	488	506	526	546	562	608	642	662	98.0	1.5	0.5
64	358	398	418	444	468	490	504	524	544	570	606	638	658	98.0	1.5	1.5
65	360	398	420	448	468	488	506	528	550	578	618	656	666	97.0	2.0	1.0
66	398	420	446	462	462	510	528	548	570	584	622	660	660	96.5	2.0	1.5
67	358	392	420	446	465	490	500	520	540	567	605	646	648	96.5	1.5	2.0
68	358	398	416	442	462	480	496	516	536	562	604	648	652	97.0	2.0	1.0
69	356	390	412	438	460	480	500	520	542	568	606	642	654	97.0	2.0	1.0
70	360	390	410	436	454	470	490	508	526	554	596	642	654	97.5	1.5	1.0
71	346	376	400	426	446	466	484	506	524	552	594	626	640	97.2	1.8	1.0
72	366	392	412	436	454	474	494	514	536	562	600	630	648	97.5	1.5	1.0
73	334	370	396	416	434	452	470	490	510	542	592	636	0	97.5	1.5	1.0
74	360	384	402	428	446	466	486	504	530	558	596	632	654	97.5	1.5	1.0
75	352	376	398	424	442	462	482	504	526	556	596	624	650	97.5	1.5	1.0
76	346	370	386	402	416	428	442	456	472	494	528	566	596	97.0	1.8	1.2
77	362	380	392	410	426	440	456	476	516	524	562	620	634	97.2	1.8	1.0
78	346	364	390	410	428	444	462	480	502	528	572	616	630	97.5	1.5	1.0
79	342	380	398	418	438	454	472	494	516	546	598	628	636	97.0	2.0	1.0
80	342	380	398	418	438	454	472	494	516	546	598	628	636	97.0	2.0	1.0
AVG	343	385	408	434	454	472	490	509	530	556	595	630	644	97.2	2.2	0.8
SD	46	31	24	17	17	18	19	19	20	21	21	17	18	1.4	0.8	0.6
CV	13	8	6	4	4	4	4	4	4	4	3	3	3	1.4	37.3	71.2
ALL	336	0	398	423	442	461	483	501	522	546	585	600	635	98.8	1.1	0.1

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APPENDIX D

EXPERIMENTAL PROCEDURES

This Section describes the experimental, analytical, and calibration procedures used to obtain the emissions data. Procedures for the extract chemical identification work are presented in Section 8.

VEHICLE EMISSIONS TESTING

Gaseous emissions and fuel consumption were measured by the 1979 EPA procedures simultaneously with particulate sampling by the 1981 EPA procedures. The vehicle test bay was maintained at constant temperature by two air conditioning/-heating/humidification/dehumidification units with a combined capacity of 106 kw and circulating 425 m^3/min conditioned air onto the vehicle positioned on the dynamometer.

Dilution tunnel sampling has come into general use for measurement of diesel particulate mass emissions, and particulate samples collected by this method have also been widely used for further particulate characterization. While the potential for chemically reactive species to contribute artifacts in dilution tunnel filter collection has been noted (64-67), dilution tunnel sample collection has become the accepted choice in lieu of any proven sampling procedure. Recent work (68) has provided some guidelines for dilution tunnel sampling to minimize the potential artifactual formation of direct-acting mutagens during the sampling process due to the presence of NO_2 in the exhaust gas. Thus while all reasonable experimental care was exercised, it must be noted that sampling procedures valid for emissions measurement cannot be extrapolated to be quantitative sampling procedures for all chemical species present. Since the chemical identity of all emission products are not known, the degree to which the emission chemistry interacts with sampling procedures cannot be quantitatively evaluated.

Particulate Emissions Measurement

Collection Apparatus —

Particulate emissions were measured according to 1981 EPA procedures (69) for new vehicle certification using a positive displacement pump (PDP) for air dilution of the vehicle exhaust, followed by particulate sampling in a dilution tunnel. To obtain samples of sufficient size for subsequent chemical and bioassay analyses from short vehicle tests, a scaled-up particulate sampling system was added to the dilution tunnel. Figure D-1 is a schematic of the exhaust dilution and particulate sampling equipment. Particulate mass emissions for vehicle tests were determined by proportional sampling of dilute exhaust by either of two identical 47 mm filter systems.

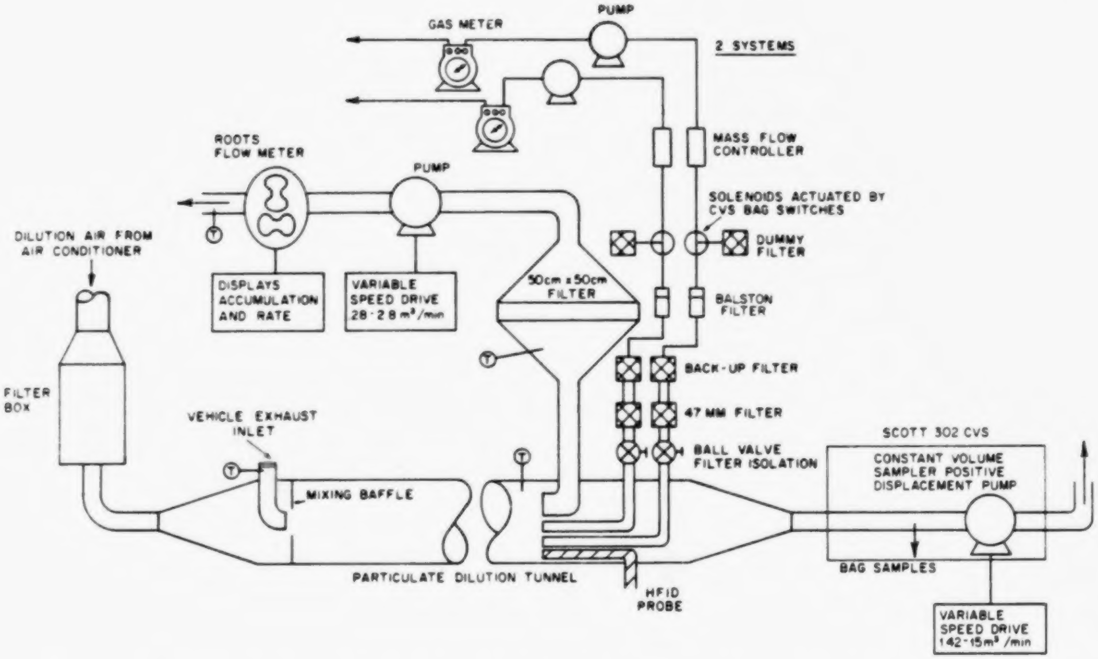
PUMP
GAS METER
2 SYSTEMS
ROOTS FLOW METER
PUMP
MASS FLOW CONTROLLER
SOLENOIDS ACTUATED BY CVS BAG SWITCHES
DILUTION AIR FROM AIR CONDITIONER
DUMMY FILTER
DISPLAYS ACCUMULATION AND RATE
VARIABLE SPEED DRIVE 28-2.8 m³/min
50cm x 50cm FILTER
BALSTON FILTER
BACK-UP FILTER
FILTER BOX
VEHICLE EXHAUST INLET
47 MM FILTER
SCOTT 302 CVS
BALL VALVE FILTER ISOLATION
CONSTANT VOLUME SAMPLER POSITIVE DISPLACEMENT PUMP
MIXING BAFFLE
BAG SAMPLES
PARTICULATE DILUTION TUNNEL
HFID PROBE
VARIABLE SPEED DRIVE 142-15m³ /min
T

Figure D-1. Schematic of Particulate Collection Apparatus.

Each filter could be isolated from the probe and dilution tunnel by smooth-bore ball valves to permit changing filters during vehicle testing. Each 47 mm filter was equipped with an identical 47 mm backup filter immediately downstream of the primary filter. Constant sampling flow was maintained as particulate was progressively deposited on the filter by means of mass flow controllers (Tylan Model FC-202) capable of maintaining constant mass flow over a wide range of gas temperatures and pressures. These flow controllers operated from a common power supply and display panel, and had individually adjustable mass flow rate set-points. These independent probe systems were flow calibrated each week with a Meriam laminar flow element (#50 MJ10).

The particulate sampling system for obtaining bulk samples for extraction used a filter assembly developed by EPA employing a 50 cm x 50 cm (20 in x 20 in) square filter. A nominal flow of 2.8 m^3/min (100 cfm) was drawn through this filter to yield 0.5 to 2 g of particulate from typical vehicle tests. The dilute exhaust passing through the 50 cm x 50 cm filter was measured by a Roots-type totalizing flow meter (Dresser Industries Model 5M125) mounted on the vent side of the blower used to draw sample through the filter (Figure D-1). The volume filtered through the 50 cm x 50 cm system during emissions testing was obtained from a digital accumulator on the Roots meter actuated in synchronization with other sampling devices by the CVS bag fill switches. Continuously recorded temperatures at the Roots meter exit were used to correct the volumetric data to standard conditions. Thus, routine mass emission tests could be performed simultaneously with bulk particulate collection for further chemical characterization. Propane tests with both CVS and 50 cm x 50 cm filter operating verified the flow measurement calibration of the complete system.

The filter used in both the 47 mm and 50 cm x 50 cm filter systems were Pallflex Products Corporation Type T60A20 teflon coated glass fiber. The nominal flows of the 47 mm and 50 cm x 50 cm systems were 9 l/min and 2.26 x 10^3 l/min respectively, referenced to 0°C. Dilute exhaust flows per area of filter exposure were thus 0.014 l/sec/cm^2 and 0.018 l/sec/cm^2 for the 47 mm and 50 cm x 50 cm filters respectively; both within the EPA specified range for particulate measurement (0.00951 > flow > 0.0272 l/sec/cm^2 at 0°C). Operation of the 50 cm x 50 cm filter in conjuction with the CVS required the 50 cm x 50 cm system to be started before the CVS to avoid filter tearing. This operational constraint made it impossible to select only a portion of any given driving cycle for bulk sample collection since the filter flow had to begin before CVS start-up and extend past CVS shut-down.

The maximum allowable temperature of dilute exhaust for particulate sampling by EPA procedure is 52°C; and this constraint directly affects the volume of dilution air necessary to cool the vehicle exhaust prior to sampling. Sampling requirements for the variety of vehicles, engine sizes, inertia weights, and vehicle operating modes encountered in this study were best met by using a range of dilution air flows. The need to obtain measurable levels of gaseous species simultaneously with particulate sampling prevented setting the dilution air flow at one high value to satisfy only the particulate temperature limit sampling requirements. To accommodate these needs, an existing PDP - CVS was modified by addition of a 7.5 kw variable frequency three-phase motor controller to give a variable speed motor drive providing continuous adjustment of CVS flow between 1.5-15 m^3/min (50-525 cfm). In combination with the 2.8 m^3/min (100 cfm) bulk particulate sampler flow and the conditioned-air ducted to the dilution air filter box, the range of CVS flows available satisfied the 52°C maximum temperature requirement for all vehicle test conditions. Combined CVS and 50 cm x 50 cm filter flows have been consistently set to give a total dilute exhaust flow of 11.4 m^3/min (400 cfm) for Volkswagen and 17 m^3/min (600 cfm) for Mercedes-Benz and General Motors vehicles respectively. Strip chart recordings of dilute exhaust temperatures were obtained for all tests. The PDP-CVS blower and Roots meter for measurement of 50 cm x 50 cm filter flow were mass flow calibrated as a function of blower speed, using turbine flow meter standards from Autotronics Corp. (Models 100P-750-MNYNV and 100-450-SFN6-8, respectively.

Connection between the vehicle tailpipe and the dilution tunnel was either by a short length (approximately 1 m) of 7.6 cm (3 in) uninsulated flexible exhaust tube for vehicles with tailpipe exhaust near the tunnel (passenger side), or by a longer connector to vehicles with a tailpipe connector on the side of the vehicle opposite the tunnel location (driver side). Two types of connector were utilized in this latter case. Through the first 17 vehicle tests, this connector was of the same type as above, but of sufficient length (4 m) to reach the tailpipe. For subsequent vehicle tests a smooth stainless steel tube (7.6 cm x 3 m), lagged with 5 cm of fiberglass insulation, was used to link the tunnel to the tailpipe with short flexible uninsulated sections to make the connections. Particulate emission tests with the insulated and uninsulated systems showed approximately a 5% mass increase for the insulated case. EPA has also reported (70) on the effect of tailpipe hookup on observed particulate emissions.

After nine months of daily testing the dilution tunnel was carefully cleaned. From the weight of tunnel scrapings and an estimate of the total mass of particulate entering the tunnel throughout the course of testing, the particulate losses in the tunnel were estimated to be 3%.

Weighing of Filters--

The 47 mm diameter Pallflex filters were placed in a constant humidity chamber for at least 24 hours before each weighing. Chamber temperature was maintained at 18 to 21°C with a relative humidity range of 55 to 60%. The equilibrated filters weights, in micrograms, were obtained on a Mettler ME 30 microbalance. The 50 cm x 50 cm filters were not environmentally equilibrated, but were stored in areas where the temperature was usually about 20°C and the relative humidity was in the 30 to 50% range. Tare weights were taken by carefully rolling the filters into approximately 15 cm cylinders and placing them on a semicircular weighing pan in a Mettler H10T balance. The balance doors were kept open to accommodate the length of the rolled filters. The balance itself was in a large five-sided box to reduce air currents and the weighings were performed in a balance room without air circulation. Gross weights were taken after the filters had been folded into quarters and were performed in a normal manner. Weights were taken to the nearest milligram with the uncertainty in the net weight estimated to be about ± 5 mg.

Extraction of Filters--

The 50 cm x 50 cm filters used for bulk particle collection were extracted with dichloromethane to obtain the extract as a percentage of the particulate mass on the 50 cm x 50 cm filters. The filters were folded and placed in 50 mm Soxhlet extractors without thimbles. Extraction was carried out with approximately 300 ml of dichloromethane (Burdick and Jackson Laboratories, Distilled in Glass^{TM} grade) for 24 hours at three to four cycles per hour.

The extracts were vacuum filtered into 500 ml flasks through an 0.2 μm Fluoropore filter (Millipore FGLP) to remove any particles which may have carried over. The solution was heated to boiling before filtering, and the filtering apparatus was kept hot during filtration to prevent precipitation of any sparingly soluble material on the filter. The 500 ml flasks were rotary evaporated to about 75 ml volume and the sample transferred to acid and solvent washed, dried and tared 125 ml borosilicate glass bottles with Teflon lined caps. These bottles were then partially immersed in a warm water bath while attached to the rotary evaporator to remove the remaining solvent to yield the dried extract. The bottles were maintained overnight at room temperature and a partial vacuum of about 10 in Hg in order to insure complete solvent removal. Final weighing provided, by difference, the mass of extract. Bottles with dried extract were then stored at -80°C until needed for bioassay.

For each of tests 1 to 34 there were twenty-one 50 cm x 50 cm filters, 15 of which were extracted and the remainder kept in -80°C storage. The six unextracted filters were the CFDS and HFET filters from the afternoon portion of each phase. For tests 35 to 80 all 12 filters were extracted.

Particulate Backup Filters--

Twelve vehicle tests have been conducted with backup filters for every 47 mm filter collected to investigate their importance for the various vehicles, fuels, and driving schedules. Average backup filter contribution to the combined mass (primary plus backup) was 1.65% ($\sigma = 0.95$) for 295 individual test cycles (i.e. 295 separate filters). The backup contribution for FTP testing was 2.66% ($\sigma = 1.6$) for 96 observations. The group of filters with the highest backup contribution came from the IDLE test mode, where 35 tests gave backup contributions that averaged 5.68%

($\sigma = 5.75$). Prior to the time of this finding for the IDLE test, the CVS flow setting had been left at a constant value for all cycles for a given vehicle. This resulted in the IDLE test sampling being conducted at a significantly higher exhaust dilution ratio than the other cycles used. Backup filters from IDLEs under these conditions frequently gave higher absolute mass loadings than for those for other (higher speed) driving cycles. The collection efficiency for filter media is known to be increased by previously deposited particulate on the filter. With the very dilute exhaust of the IDLE the primary filter never received sufficient mass loading for this efficiency enhancement to occur. A subsequent decision to decrease the dilution ratio for IDLEs increased the primary filter loadings and decreased the backup filter loading.

In contrast to the general findings that backup filters collected a small percentage of the total particulate, tests on a Peugeot (Car #17) exhibited distinctly different results. Particulate from this vehicle did not mat on the face of the filter media but penetrated to give a grey appearance on both the front and back of the filter. Backup filters on 30 Peugeot test cycles averaged 9.4% of the total particulate mass. In 7 Peugeot tests, two 50 cm x 50 cm sheets were used in series in the same holder to effect a filter backup for the bulk sampler. The second 50 cm x 50 cm filter from these tests contained an average of 9.5% of the total. This observation parallels that of the EPA for a Peugeot vehicle (71, 72). Backup filters have been discontinued for all vehicles except the Peugeot, but variations in sampling conditions and vehicle type can impact the need for backup filters.

Particulate Emissions Reproducibility--

Within each test phase of the first 34 tests, the duplicate CFDS and HFET cycles performed in the afternoon and again the following morning, have been compared to determine the stability of particulate emissions during the given phase. Table (D-1) shows the reproducibility for these two driving cycles for each vehicle test phase for all 34 tests and also by vehicle make subcategory. On the average, the reproducibility is in the 1-3% range, but the standard deviations for the sample are in the 5-15% range. The Volkswagens show a larger standard deviation than other groups, possibly due to their manual transmissions in contrast to the automatic transmissions on most other sample group vehicles.

TABLE D-1. PARTICULATE EMISSIONS REPRODUCIBILITY FOR DUPLICATE CYCLES*

	OBS. IN EACH AVERAGE	Difference Between Duplicate Cycles ±1 σ PHASE 1		PHASE 2		PHASE 3		THREE PHASE AVERAGE	
		CFDS	HFET	CFDS	HFET	CFDS	HFET	CFDS	HFET
ALL TESTS	34	1.0%± 8.8	1.2%±10.6	0.1%±10.2	1.8%±8.1	1.2%± 9.2	0.8%±8.0	0.7%	1.3%
GENERAL MOTORS	16	0.5%± 7.2	2.7%± 9.0	-1.2%± 7.5	0.0%±6.3	0.6%± 5.8	1.3%±5.5	0.8%	1.7%
VOLKSWAGEN	10	1.0%±12.3	1.8%±14.9	3.5%±15.7	0.6%±7.2	2.9%±13.4	3.7%±9.2	2.5%	2.0%
MERCEDES-BENZ	4	1.8%± 8.3	-5.7%± 7.9	-0.3%± 5.6	-3.6%±3.4	3.1%± 8.8	0.2%±2.0	1.7%	-3.2%

*First 34 tests only.

Note: % > 0 indicates first cycle > second cycle.
% < 0 indicates first cycle < second cycle.

Filter Pair Correspondence--

The two independent 47 mm diameter filter collection systems were routinely operated simultaneously during all CFDS cycles after vehicle test 14 as an ongoing check of correspondence and data integrity for these systems. For 126 CFDS tests with duplicate particulate measurement by both 47 mm systems, the average ratio of the two results was 0.997±5.4%, indicating acceptable performance of this system.

The 50 cm x 50 cm bulk particulate collection system was designed to obtain significant quantities of particulate for chemical and biological analyses, and as such was not designed to insure strict gravimetric correspondence with the 47 mm diameter filter system. However, the measurements taken to provide a particulate emission value can be compared to the 47 mm value used for reported vehicle emissions. While this comparison could be made on all test cycles, here we present the comparison for only the CFDS tests. The mean absolute difference of the 50 cm x 50 cm particulate emission rate referenced to the 47 mm system for 157 CFDS tests was -0.04 g/mi, indicating a small but systematic lower collection rate by the bulk particulate system. Expressed in terms of a ratio of the 50 cm x 50 cm to 47 mm system, this becomes 0.912±6.5%.

Gaseous Emissions Measurement

Analytical Instrumentation--

Analytical instruments for measurement of gaseous emission components were:

Gas	Method	Instrument
CO_2	NDIR	Horiba AIA21
CO	NDIR	Horiba AIA21AS
NO_x	Chemiluminescence	Beckman 951
HC-background	Unheated FID	Scott 215
HC-continuous dilute	Heated FID	Horiba 1X

Zero and span checks were performed before each test cycle with gases which were referenced to primary standards five times during the course of this project.

The heated FID for dilute exhaust HC measurements used a 1/4" diameter stainless steel heated probe, followed by a heated filter and heated transfer line to the detector unit. The probe system was fitted with an "overflow zero gas/span gas" system to permit instrument calibration through the heated line input. The sample pump and FID burner assembly were located in an oven. All sample lines, filter, and oven were maintained at 191°C. Thermocouples with digital readouts were used to monitor all of these temperatures. The sample probe was located just off the centerline of the dilution tunnel (near to the particulate probes) approximately 8 tunnel diameters downstream from the exhaust inlet. Data from the heated FID were recorded on an integrating strip chart for visual display and electronically integrated and printed for each vehicle test cycle through circuit controls on the CVS console.

Other gaseous analyses were performed in a console, which contained sample handling, detectors, strip chart recorders and operator controlled zero/span devices. All sample handling equipment was either Teflon or stainless steel. Individual instrument sample flow was monitored by a flowmeter and regulated in the instrument inlet line. All instruments operated with positive pressure at the inlet ports. Instruments were each individually vented to a common non-pressurized exhaust system. Dilute exhaust from the CVS reported teflon bag samples was dried and filtered upon entry to the analytical bench, and filtered once more upon entry to each particular instrument.

All zero, span, sample, and calibration outputs from the instruments were continuously recorded for each instrument. The daily schedule of instrument operation began with a zero and span check before Bag 1 of the FTP and again in Bag 2. They were subsequently zeroed/spanned before alternate test cycles throughout the day. Each instrument main span check was followed by a second span gas check on a different instrument range to check range-to-range correspondence.

Instrument Calibration

Gaseous instrumentation was calibrated on a monthly basis using laboratory gas standards referenced to NBS. A Horiba gas divider (Model S-TEC, SGD-78) was used to provide various calibration gas blends on which the instrument calibration was fixed. The span gases for daily instrument checks were then named as part of the calibration process.

Analysis instrumentation was also checked by participation in a subscription cross-reference service of Scott Research. Seven cross-reference tests were performed during the project, and the results of AEL determinations compared to results reported by Scott Research are tabulated below as full-scale percentage error:

	Cross-reference, % Error
HC	0.17
CO	-1.02
CO_2	-1.19
NO	-2.14
NO_x	-1.24

Propane Tests--

Each day of vehicle testing began with a propane injection/recovery test that provided a check of the exhaust handling equipment as measured by the real-time heated FID detection system. Propane was injected into the exhaust port of the particulate dilution tunnel by a critical flow orifice device (Horiba CFO-201) for a period of 10 minutes. The injection tests were performed with the variable speed CVS blower operating at the designated speed for the day's test. The results of 247 propane tests are presented in Table D-2 below by the two main blower speeds:

Table D-2. Propane Injection Test Results

Classification	LOW SPEED (315 cfm)	HIGH SPEED (508 cfm)	Composite
	Observed Percentages		
Total No. of Tests	28	72	100
% Error ≥ 0%	53	34	39
% Error ≤ 0%	47	66	61
% Error > +2%	7	6	6
% Error < -2%	1	23	17
-2% ≤ % Error ≤ +2%	91	71	77

Thus 71% and 91% of the respective high and low blower speed propane tests were within ±2% recovery limits giving a composite project value of 77%.

DYNAMOMETER

The chassis dynamometer used throughout the project was a Clayton CTE50, equipped with automatic road-load and direct-drive variable inertia (250 lb increments to 3,000 lb, 500 lb increments above 3,000 lb) features. The dynamometer was warmed up each day before testing with a 15 min 50 mph cruise, during which time the road-load setting for that test was established and the drivers aid recorder calibration checked. Three periodic complete dynamometer calibrations were performed during this project by a coast-down procedure. Coast-downs were recorded on a strip-chart recorder and timed to give four load points for each inertia setting. This calibration was stored as a linear regression to permit load/inertia specifications to be readily selected and checked.

IN-USE VEHICLE HANDLING

Upon delivery to AEL for testing, an in-use vehicle was first checked for sufficient tank fuel to complete the "as-received" portion of testing. If insufficient, additional commercial diesel fuel was added, usually 5-10 gallons from a local vendor. A one liter sample of tank fuel sample was then pumped from the tank and sent out for fuel analysis. An additional fuel sample was also taken for project archives.

Engine oil and transmission level were then checked to verify acceptance for testing. The drive tires were removed and replaced with AEL tires of vehicle manufacturer specification inflated to 45 psig. This procedure guarded against unnecessary wear on vehicle owners tires during the extensive dynamometer test (about 200 miles) and aided project results by providing a uniform test tire throughout the length of the program.

After completion of Phase 1 the engine oil was drained and a sample taken for project reference. The oil filter was changed and the crankcase refilled with oil (Castrol) of proper specifications. The oils used were:

	Summer	Winter
General Motors	30W	10W30
Volkswagen	20W50	10W30
Mercedes-Benz	20W50	10W30

At the time of oil change, the fuel was also changed to AEL control fuel. A portable auxiliary fuel tank was connected to the injector pump inlet. The vehicle was then run for 15 min at 50 mph to purge the fuel injection system back into the vehicle tank through the return line. The return line was then connected to the auxiliary tank to complete the switch over to control fuel before the next portion of testing.

APPENDIX E

EMISSION AND BIOACTIVITY CORRELATIONS

TABLE E-1. FTP Cycle - GM Vehicle Group - All Phases
TABLE E-2. FTP Cycle - VW Vehicle Group - All Phases
TABLE E-3. FTP Cycle - MB Vehicle Group - All Phases
TABLE E-4. FTP Cycle - "Other" Vehicle Group - All Phases
TABLE E-5. FTP Cycle - "All" Vehicle Group - All Phases

TABLE E-6. HFET Cycle - GM Vehicle Group - All Phases
TABLE E-7. HFET Cycle - VW Vehicle Group - All Phases
TABLE E-8. HFET Cycle - MB Vehicle Group - All Phases
TABLE E-9. HFET Cycle - "Other" Vehicle Group - All Phases
TABLE E-10. HFET Cycle - "All" Vehicle Group - All Phases

TABLE E-11. CFDS Cycle - GM Vehicle Group - All Phases
TABLE E-12. CFDS Cycle - VW Vehicle Group - All Phases
TABLE E-13. CFDS Cycle - MB Vehicle Group - All Phases
TABLE E-14. CFDS Cycle - "Other" Vehicle Group - All Phases
TABLE E-15. CFDS Cycle - "All" Vehicle Group - All Phases

TABLE E-16. New York City Cycle - GM Vehicle Group - All Phases
TABLE E-17. New York City Cycle - VW Vehicle Group - All Phases
TABLE E-18. New York City Cycle - MB Vehicle Group - All Phases
TABLE E-19. New York City Cycle -"Other" Vehicle Group - All Phases
TABLE E-20. New York City Cycle - "All" Vehicle Group - All Phases

TABLE E-21. IDLE Cycle - GM Vehicle Group - All Phases
TABLE E-22. IDLE Cycle - VW Vehicle Group - All Phases
TABLE E-23. IDLE Cycle - MB Vehicle Group - All Phases
TABLE E-24. IDLE Cycle - "Other" Vehicle Group - All Phases
TABLE E-25. IDLE Cycle - "All Vehicle Group - All Phases

TABLE E-1. Emission and Bioactivity Correlations
FTP Cycle - GM Vehicle Group - All Phases

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           EXTRACT   RESIDUE   EXTRACT   EXTRACT   RESIDUE   RES/EXT  100K REV   REV PER   REV PER   REV PER  100K REV
            G/MILE    G/MILE    G/KG-F         %    G/KG-F     RATIO    PER MI   UG PART    UG EXT    UG RES  PER KG-F

       N        74        74        72        74        72        74        72        72        72        72        70
    MEAN     .2170     .6707    1.1429   23.5129    3.6168    3.9188    6.0317     .7111    3.6226     .9251   32.5624
 STD DEV     .1326     .1367     .6779   10.0183     .6769    1.7440    2.5353     .3461    2.2806     .4171   14.1181
   RSD %   61.0821   20.3855   59.3171   42.6078   18.7156   44.5023   42.0335   48.6719   62.9533   45.0816   43.3569

                                              CORRELATION MATRIX

             RESIDUE   EXTRACT   EXTRACT   RESIDUE   RES/EXT  100K REV   REV PER   REV PER   REV PER  100K REV
              G/MILE    G/KG-F         %    G/KG-F     RATIO    PER MI   UG PART    UG EXT    UG RES  PER KG-F

EXTRACT           74        72        74        72        74        72        72        72        72        70
G/MILE          .011      .997      .938     -.022     -.788     -.121     -.332     -.567     -.124     -.139
              SL=  0    SL=  3    SL=  3    SL=  0    SL=  3    SL=  0    SL=  3    SL=  3    SL=  0    SL=  0

          RESIDUE           72        74        72        74        72        72        72        72        70
          G/MILE         -.002     -.296      .971      .395      .052     -.236     -.011     -.318      .008
                        SL=  0    SL=  2    SL=  3    SL=  3    SL=  0    SL=  1    SL=  0    SL=  3    SL=  0

                    EXTRACT             72        72        72        70        70        70        70        70
                    G/KG-F            .945     -.040     -.793     -.122     -.318     -.554     -.122     -.139
                                    SL=  3    SL=  0    SL=  3    SL=  0    SL=  3    SL=  3    SL=  0    SL=  0
KEY:
                              EXTRACT           72        74        72        72        72        72        70
NO. OF DATA PAIRS                %           -.322     -.908     -.125     -.246     -.568     -.013     -.130
SAMPLE CORR. COEFF.                         SL=  3    SL=  3    SL=  0    SL=  1    SL=  3    SL=  0    SL=  0
SIGNIFICANCE LEVEL
                                        RESIDUE           72        70        70        70        70        70
                                        G/KG-F          .408      .059     -.210      .023     -.294      .045
SIGNIFICANCE LEVELS:                                  SL=  3    SL=  0    SL=  1    SL=  0    SL=  2    SL=  0

SL = 1 FOR 0.05≥ALPHA>0.01                        RES/EXT           72        72        72        72        70
SL = 2 FOR 0.01≥ALPHA>0.005                       RATIO           .063      .129      .545     -.089      .062
SL = 3 FOR 0.005≥ALPHA                                          SL=  0    SL=  0    SL=  3    SL=  0    SL=  0

                                                            100K REV          72        72        72        70
                                                            PER MI          .926      .795      .924      .993
                                                                          SL=  3    SL=  3    SL=  3    SL=  3

                                                                      REV PER           72        72        70
                                                                      UG PART         .877      .970      .941
                                                                                    SL=  3    SL=  3    SL=  3

                                                                                REV PER           72        70
                                                                                UG EXT          .752      .813
                                                                                              SL=  3    SL=  3

                                                                                          REV PER           70
                                                                                          UG RES          .937
                                                                                                        SL=  3
```

TABLE E-2. Emission and Bioactivity Correlations
FTP Cycle - VW Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	47	47	47	48	47	47	45	46	47	45	45
MEAN	.0741	.2957	.8505	20.6472	3.3890	4.4735	6.6690	1.7903	10.3921	2.2247	76.5419
STD DEV	.0275	.0699	.3180	7.3134	.7917	1.7343	4.8969	1.1643	8.3799	1.4255	56.5676
RSD %	37.1518	23.6457	37.3865	35.4208	23.3598	38.7695	73.4283	65.0344	80.6376	64.0769	73.9041

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	47 .679 SL= 3	47 -.273 SL= 1	47 .666 SL= 3	48 .758 SL= 3	47 -.279 SL= 1	47 -.644 SL= 3	45 -.038 SL= 0	46 .018 SL= 0	47 -.265 SL= 1	45 .127 SL= 0
RESIDUE G/MILE		47 .052 SL= 0	47 .994 SL= 3	47 .783 SL= 3	47 .055 SL= 0	47 -.768 SL= 3	45 .017 SL= 0	45 -.105 SL= 0	45 -.386 SL= 3	45 .014 SL= 0
EXTRACT G/KG-F			47 .040 SL= 0	47 -.534 SL= 3	47 .987 SL= 3	47 .543 SL= 3	45 .407 SL= 3	45 .175 SL= 0	45 .331 SL= 1	45 .091 SL= 0
EXTRACT %				47 .785 SL= 3	47 .060 SL= 0	47 -.770 SL= 3	45 .033 SL= 0	45 -.083 SL= 0	45 -.373 SL= 2	45 .038 SL= 0
RESIDUE G/KG-F					47 -.529 SL= 3	47 -.944 SL= 3	45 -.225 SL= 0	46 -.154 SL= 0	46 -.507 SL= 3	45 -.020 SL= 0
RES/EXT RATIO						47 .530 SL= 3	45 .433 SL= 3	45 .208 SL= 0	45 .355 SL= 2	45 .125 SL= 0
100K REV PER MI							45 .279 SL= 1	45 .250 SL= 1	45 .583 SL= 3	45 .106 SL= 0
REV PER UG PART								45 .945 SL= 3	45 .871 SL= 3	45 .922 SL= 3
REV PER UG EXT									46 .904 SL= 3	45 .985 SL= 3
REV PER UG RES										45 .833 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05≥ALPHA>0.01
SL = 2 FOR 0.01≥ALPHA>0.005
SL = 3 FOR 0.005≥ALPHA

TABLE E-3. Emission and Bioactivity Correlations
FTP Cycle - MB Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	21	21	20	21	20	21	19	19	20	19	18
MEAN	.0790	.4549	.5549	15.1317	2.9909	6.9574	3.3036	.6159	5.3350	.7111	21.8326
STD DEV	.0346	.0892	.2858	7.2381	.4068	3.0782	1.6641	.2913	3.4920	.3266	11.2781
RSD %	43.8684	19.6059	51.5053	47.8343	13.6025	44.2441	50.3720	47.3033	65.4543	45.9320	51.6572

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	21 -.448 SL= 1	20 .990 SL= 3	21 .958 SL= 3	20 -.132 SL= 0	21 -.931 SL= 3	19 -.322 SL= 0	19 -.357 SL= 0	19 -.655 SL= 3	19 -.225 SL= 0	18 -.218 SL= 0
RESIDUE G/MILE		20 -.512 SL= 2	21 -.667 SL= 3	20 .865 SL= 3	21 .666 SL= 3	19 .285 SL= 0	19 .028 SL= 0	19 .289 SL= 0	19 -.060 SL= 0	18 .166 SL= 0
EXTRACT G/KG-F			20 .973 SL= 3	20 -.179 SL= 0	20 -.951 SL= 3	18 -.320 SL= 0	18 -.331 SL= 0	18 -.647 SL= 3	18 -.196 SL= 0	18 -.192 SL= 0
EXTRACT %				20 -.380 SL= 1	21 -.962 SL= 3	19 -.351 SL= 0	19 -.303 SL= 0	19 -.648 SL= 3	19 -.159 SL= 0	18 -.224 SL= 0
RESIDUE G/KG-F					20 .320 SL= 0	18 .283 SL= 0	18 .032 SL= 0	18 .108 SL= 0	18 -.008 SL= 0	18 .245 SL= 0
RES/EXT RATIO						19 .386 SL= 0	19 .330 SL= 0	19 .719 SL= 3	19 .193 SL= 0	18 .242 SL= 0
100K REV PER MI							19 .956 SL= 3	19 .853 SL= 3	19 .932 SL= 3	18 .978 SL= 3
REV PER UG PART								19 .851 SL= 3	19 .987 SL= 3	18 .964 SL= 3
REV PER UG EXT									19 .766 SL= 3	18 .768 SL= 3
REV PER UG RES										18 .965 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-4. Emission and Bioactivity Correlations
FTP Cycle - "Other" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	35	35	34	36	34	35	32	33	33	32	31
MEAN	.2569	.3761	1.6254	39.6125	2.4355	1.9545	7.8413	1.1869	3.7545	2.1107	50.8091
STD DEV	.1506	.1484	.7581	16.5608	.9893	1.1892	5.3690	.7015	2.7582	1.5152	33.1915
RSD %	58.6080	39.4561	46.6372	41.8069	40.6202	60.8442	68.4708	59.1058	73.4623	71.7881	65.3259

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	35 -.238 SL= 0	34 .949 SL= 3	35 .821 SL= 3	34 -.394 SL= 1	35 -.725 SL= 3	32 .396 SL= 1	32 .035 SL= 0	32 -.419 SL= 2	32 .554 SL= 3	31 .190 SL= 0
RESIDUE G/MILE		34 -.301 SL= 1	35 -.685 SL= 3	34 .920 SL= 3	35 .697 SL= 3	32 .229 SL= 0	32 .069 SL= 0	32 .339 SL= 1	32 -.175 SL= 0	31 .303 SL= 1
EXTRACT G/KG-F			34 .867 SL= 3	34 -.368 SL= 1	34 -.808 SL= 3	31 .316 SL= 1	31 -.035 SL= 0	31 -.478 SL= 3	31 .465 SL= 3	31 .174 SL= 0
EXTRACT %				34 -.751 SL= 3	35 -.952 SL= 3	32 .074 SL= 0	33 -.106 SL= 0	33 -.559 SL= 3	32 .383 SL= 1	31 -.099 SL= 0
RESIDUE G/KG-F					34 .729 SL= 3	31 .196 SL= 0	31 .125 SL= 0	31 .447 SL= 2	31 -.224 SL= 0	31 .351 SL= 1
RES/EXT RATIO						32 -.013 SL= 0	32 .128 SL= 0	32 .605 SL= 3	32 -.325 SL= 1	31 .120 SL= 0
100K REV PER MI							32 .858 SL= 3	32 .572 SL= 3	32 .891 SL= 3	31 .952 SL= 3
REV PER UG PART								33 .814 SL= 3	32 .815 SL= 3	31 .897 SL= 3
REV PER UG EXT									32 .367 SL= 1	31 .711 SL= 3
REV PER UG RES										31 .782 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-5. Emission and Bioactivity Correlations
FTP Cycle - "All" Vehicle Group - All Phases

```
          EXTRACT  RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER 100K REV
          G/MILE   G/MILE   G/KG-F      %     G/KG-F    RATIO   PER MI  UG PART   UG EXT   UG RES  PER KG-F

     N       177      177      173      179      173      177      168      170      172      168      164
  MEAN     .1706    .4873   1.0903  24.9990   3.2503   4.0381   6.2385   1.0848   5.6968   1.4748  46.9007
STD DEV    .1337    .2018    .6655  13.2587    .8739   2.3097   4.0300    .8575   5.6958   1.2135  39.5901
 RSD %   78.3824  41.4117  61.0331  53.0370  26.8871  57.1986  64.5985  79.0421  99.9833  82.2820  84.4126


                                     CORRELATION MATRIX

               RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER 100K REV
               G/MILE   G/KG-F      %     G/KG-F    RATIO   PER MI  UG PART   UG EXT   UG RES  PER KG-F


EXTRACT           177      173      177      173      177      168      168      168      168      164
G/MILE           .218     .940     .808    -.177    -.656     .159    -.219    -.427     .062    -.121
               SL= 3    SL= 3    SL= 3    SL= 2    SL= 3    SL= 1    SL= 3    SL= 3    SL= 0    SL= 0

         RESIDUE           173      177      173      177      168      168      168      168      164
         G/MILE           -.007    -.292     .686     .223     .026    -.383    -.246    -.430    -.248
                        SL= 0    SL= 3    SL= 3    SL= 3    SL= 0    SL= 3    SL= 3    SL= 3    SL= 3

                  EXTRACT           173      173      173      164      164      164      164      164
                  G/KG-F           .889    -.223    -.762     .175    -.102    -.369     .174     .001
                                 SL= 3    SL= 3    SL= 3    SL= 1    SL= 0    SL= 3    SL= 1    SL= 0
KEY:
                           EXTRACT           173      177      168      170      170      168      164
NO. OF DATA PAIRS             %             -.587    -.839     .094    -.067    -.396     .238    -.058
SAMPLE CORR. COEFF.                       SL= 3    SL= 3    SL= 0    SL= 0    SL= 3    SL= 3    SL= 0
SIGNIFICANCE LEVEL
                                    RESIDUE           173      164      164      164      164      164
                                    G/KG-F           .432     .152     .007     .206    -.189     .189
SIGNIFICANCE LEVELS:                               SL= 3    SL= 1    SL= 0    SL= 3    SL= 2    SL= 2

SL = 1 FOR 0.05>ALPHA>0.01                   RES/EXT           168      168      168      168      164
SL = 2 FOR 0.01>ALPHA>0.005                   RATIO          -.080     .050     .431    -.166     .036
SL = 3 FOR 0.005>ALPHA                                    SL= 0    SL= 0    SL= 3    SL= 1    SL= 0

                                                      100K REV           168      168      168      164
                                                       PER MI           .793     .604     .838     .854
                                                                     SL= 3    SL= 3    SL= 3    SL= 3

                                                               REV PER           170      168      164
                                                               UG PART          .870     .914     .952
                                                                              SL= 3    SL= 3    SL= 3

                                                                        REV PER           168      164
                                                                        UG EXT           .661     .832
                                                                                       SL= 3    SL= 3

                                                                                 REV PER           164
                                                                                 UG RES           .873
                                                                                                SL= 3
```

TABLE E-6. Emission and Bioactivity Correlations
HFET Cycle - GM Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	73	73	73	73	73	73	70	70	70	70	70
MEAN	.1667	.2839	1.3464	34.5636	2.2925	2.3535	2.8685	.7049	2.4129	1.0950	23.1416
STD DEV	.1263	.1069	1.0164	14.4505	.8228	1.2355	1.7010	.3807	1.5962	.5583	13.3785
RSD %	75.7550	37.6568	75.4913	41.8085	35.8894	52.4966	59.3005	54.0088	66.1529	50.9866	57.8116

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	73 .604 SL= 3	73 -.071 SL= 0	73 .615 SL= 3	73 .623 SL= 3	73 -.083 SL= 0	73 -.573 SL= 3	70 .168 SL= 0	70 -.150 SL= 0	70 -.331 SL= 3	70 .070 SL= 0
RESIDUE G/MILE		73 .089 SL= 0	73 .998 SL= 3	73 .878 SL= 3	73 .068 SL= 0	73 -.704 SL= 3	70 .096 SL= 0	70 -.296 SL= 2	70 -.514 SL= 3	70 .089 SL= 0
EXTRACT G/KG-F			73 .064 SL= 0	73 -.318 SL= 3	73 .995 SL= 3	73 .365 SL= 3	70 .147 SL= 0	70 -.281 SL= 2	70 -.117 SL= 0	70 -.397 SL= 3
EXTRACT %				73 .885 SL= 3	73 .049 SL= 0	73 -.707 SL= 3	70 .078 SL= 0	70 -.302 SL= 2	70 -.515 SL= 3	70 .079 SL= 0
RESIDUE G/KG-F					73 -.337 SL= 3	73 -.903 SL= 3	70 .077 SL= 0	70 -.150 SL= 0	70 -.489 SL= 3	70 .269 SL= 1
RES/EXT RATIO						73 .388 SL= 3	70 .122 SL= 0	70 -.295 SL= 2	70 -.117 SL= 0	70 -.422 SL= 3
100K REV PER MI							70 -.150 SL= 0	70 .008 SL= 0	70 .428 SL= 3	70 -.350 SL= 3
REV PER UG PART								70 .760 SL= 3	70 .576 SL= 3	70 .779 SL= 3
REV PER UG EXT									70 .872 SL= 3	70 .901 SL= 3
REV PER UG RES										70 .617 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-7. Emission and Bioactivity Correlations
HFET Cycle - VW Vehicle Group - All Phases

```
          EXTRACT  RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER 100K REV
           G/MILE   G/MILE   G/KG-F        %   G/KG-F    RATIO   PER MI  UG PART   UG EXT   UG RES PER KG-F

       N       46       46       46       47       46       46       45       45       46       45       45
    MEAN    .0647    .2348    .9787  22.1757   3.5455   4.1434   5.0425   1.6962   9.6739   2.1392  76.2151
STD DEV     .0268    .0670    .4102   8.4923   1.0020   1.7616   4.0125   1.3367   8.8747   1.5780  59.8309
   RSD %  41.4699  28.5412  41.9131  38.2954  28.2621  42.5157  79.5726  78.8057  91.7387  73.7682  78.5027

                                             CORRELATION MATRIX

            RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER 100K REV
             G/MILE   G/KG-F        %   G/KG-F    RATIO   PER MI  UG PART   UG EXT   UG RES PER KG-F

EXTRACT          46       46       46       46       46       45       45       45       45       45
G/MILE        -.038     .992     .788    -.038    -.719    -.207    -.299    -.431    -.219    -.221
             SL=  0   SL=  3   SL=  3   SL=  0   SL=  3   SL=  0   SL=  1   SL=  3   SL=  0   SL=  0

          RESIDUE         46       46       46       46       45       45       45       45       45
          G/MILE       -.054    -.603     .983     .653     .414     .114     .313     .038     .397
                      SL=  0   SL=  3   SL=  3   SL=  3   SL=  3   SL=  0   SL=  1   SL=  0   SL=  3

                   EXTRACT         46       46       46       45       45       45       45       45
                   G/KG-F        .789    -.033    -.721    -.212    -.290    -.428    -.208    -.219
                               SL=  3   SL=  0   SL=  3   SL=  0   SL=  1   SL=  3   SL=  0   SL=  0
KEY:
                            EXTRACT         46       46       45       45       45       45       45
NO. OF DATA PAIRS              %         -.596    -.938    -.391    -.308    -.513    -.201    -.393
SAMPLE CORR. COEFF.                     SL=  3   SL=  3   SL=  3   SL=  1   SL=  3   SL=  0   SL=  3
SIGNIFICANCE LEVEL
                                     RESIDUE         46       45       45       45       45       45
                                     G/KG-F        .646     .414     .129     .325     .055     .408
SIGNIFICANCE LEVELS:                             SL=  3   SL=  3   SL=  0   SL=  1   SL=  0   SL=  3

SL = 1 FOR 0.05>ALPHA>0.01                    RES/EXT         45       45       45       45       45
SL = 2 FOR 0.01>ALPHA>0.005                   RATIO         .414     .291     .537     .189     .415
SL = 3 FOR 0.005>ALPHA                                    SL=  3   SL=  1   SL=  3   SL=  0   SL=  3

                                                       100K REV        45       45       45       45
                                                       PER MI        .922     .948     .897     .997
                                                                   SL=  3   SL=  3   SL=  3   SL=  3

                                                                REV PER         45       45       45
                                                                UG PART       .954     .993     .930
                                                                            SL=  3   SL=  3   SL=  3

                                                                         REV PER         45       45
                                                                         UG EXT        .917     .952
                                                                                     SL=  3   SL=  3

                                                                                  REV PER         45
                                                                                  UG RES        .906
                                                                                              SL=  3
```

TABLE E-8. Emission and Bioactivity Correlations
HFET Cycle - MB Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	22	22	22	22	22	22	20	20	20	20	20
MEAN	.0573	.3299	.5298	14.9793	2.8884	7.5872	1.9613	.4988	4.7150	.5716	16.9145
STD DEV	.0320	.0569	.3419	8.5686	.3517	3.7352	.9656	.2294	2.9410	.2494	8.3363
RSD %	55.8909	17.2457	64.5285	57.2030	12.1747	49.2306	49.2323	45.9930	62.3765	43.6342	49.2849

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	22 -.549 SL= 3	22 .996 SL= 3	22 .976 SL= 3	22 -.169 SL= 0	22 -.919 SL= 3	20 -.207 SL= 0	20 -.271 SL= 0	20 -.617 SL= 3	20 -.132 SL= 0	20 -.094 SL= 0
RESIDUE G/MILE		22 -.594 SL= 3	22 -.696 SL= 3	22 .820 SL= 3	22 .659 SL= 3	20 .468 SL= 1	20 .309 SL= 0	20 .412 SL= 1	20 .246 SL= 0	20 .381 SL= 1
EXTRACT G/KG-F			22 .984 SL= 3	22 -.193 SL= 0	22 -.928 SL= 3	20 -.237 SL= 0	20 -.289 SL= 0	20 -.636 SL= 3	20 -.150 SL= 0	20 -.113 SL= 0
EXTRACT %				22 -.339 SL= 0	22 -.937 SL= 3	20 -.316 SL= 0	20 -.339 SL= 0	20 -.659 SL= 3	20 -.205 SL= 0	20 -.198 SL= 0
RESIDUE G/KG-F					22 .230 SL= 0	20 .455 SL= 1	20 .265 SL= 0	20 .124 SL= 0	20 .266 SL= 0	20 .478 SL= 1
RES/EXT RATIO						20 .186 SL= 0	20 .215 SL= 0	20 .627 SL= 3	20 .085 SL= 0	20 .053 SL= 0
100K REV PER MI							20 .972 SL= 3	20 .794 SL= 3	20 .968 SL= 3	20 .982 SL= 3
REV PER UG PART								20 .854 SL= 3	20 .989 SL= 3	20 .953 SL= 3
REV PER UG EXT									20 .779 SL= 3	20 .699 SL= 3
REV PER UG RES										20 .969 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-9. Emission and Bioactivity Correlations
HFET Cycle - "Other" Vehicle Group - All Phases

```
           EXTRACT   RESIDUE   EXTRACT   EXTRACT   RESIDUE   RES/EXT  100K REV   REV PER   REV PER   REV PER  100K REV
            G/MILE    G/MILE    G/KG-F         %    G/KG-F     RATIO    PER MI   UG PART    UG EXT    UG RES  PER KG-F

       N        37        37        37        37        37        37        33        33        33        33        33
    MEAN     .1586     .2108    1.4139   45.6840    1.9410    1.8384    4.9655    1.2695    4.2182    2.4515   46.3749
 STD DEV     .0723     .1206     .6372   21.0105    1.1951    1.5448    3.8992     .8516    4.1441    1.8843   39.4068
   RSD %   45.5895   57.2121   45.0684   45.9908   61.5696   84.0298   78.5262   67.0806   98.2434   76.8630   84.9787

                                              CORRELATION MATRIX

                RESIDUE   EXTRACT   EXTRACT   RESIDUE   RES/EXT  100K REV   REV PER   REV PER   REV PER  100K REV
                 G/MILE    G/KG-F         %    G/KG-F     RATIO    PER MI   UG PART    UG EXT    UG RES  PER KG-F

EXTRACT              37        37        37        37        37        33        33        33        33        33
G/MILE            -.492      .961      .795     -.542     -.743     -.076     -.116     -.472      .436     -.163
                SL=  3    SL=  3    SL=  3    SL=  3    SL=  3    SL=  0    SL=  0    SL=  3    SL=  2    SL=  0

     RESIDUE                       37        37        37        37        33        33        33        33        33
     G/MILE                     -.478     -.888      .973      .840      .542      .315      .631     -.233      .566
                               SL=  3    SL=  3    SL=  3    SL=  3    SL=  3    SL=  1    SL=  3    SL=  0    SL=  3

               EXTRACT                       37        37        37        33        33        33        33        33
               G/KG-F                      .765     -.473     -.687      .007     -.041     -.381      .442     -.052
                                         SL=  3    SL=  3    SL=  3    SL=  0    SL=  0    SL=  1    SL=  3    SL=  0
KEY:
                         EXTRACT                       37        37        33        33        33        33        33
NO. OF DATA PAIRS           %                       -.894     -.940     -.407     -.274     -.654      .361     -.463
SAMPLE CORR. COEFF.                                SL=  3    SL=  3    SL=  2    SL=  0    SL=  3    SL=  1    SL=  3
SIGNIFICANCE LEVEL
                                   RESIDUE                       37        33        33        33        33        33
                                   G/KG-F                      .875      .609      .405      .714     -.178      .654
SIGNIFICANCE LEVELS:                                         SL=  3    SL=  3    SL=  2    SL=  3    SL=  0    SL=  3

SL = 1 FOR 0.05>ALPHA>0.01                   RES/EXT                       33        33        33        33        33
SL = 2 FOR 0.01>ALPHA>0.005                   RATIO                      .434      .311      .707     -.249      .480
SL = 3 FOR 0.005>ALPHA                                                 SL=  2    SL=  1    SL=  3    SL=  0    SL=  3

                                                       100K REV                       33        33        33        33
                                                        PER MI                      .944      .863      .608      .989
                                                                                  SL=  3    SL=  3    SL=  3    SL=  3

                                                                 REV PER                       33        33        33
                                                                 UG PART                     .838      .719      .934
                                                                                           SL=  3    SL=  3    SL=  3

                                                                           REV PER                       33        33
                                                                           UG EXT                      .279      .894
                                                                                                     SL=  0    SL=  3

                                                                                     REV PER                       33
                                                                                     UG RES                      .531
                                                                                                               SL=  3
```

TABLE E-10. Emission and Bioactivity Correlations
HFET Cycle - "All" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	178	178	178	179	178	178	168	168	169	168	168
MEAN	.1251	.2617	1.1645	31.2021	2.6168	3.3558	3.7547	1.0568	5.0141	1.5788	41.1794
STD DEV	.1016	.1032	.8032	17.4162	1.0992	2.6141	3.1477	.9402	5.9407	1.3882	43.1931
RSD %	81.1958	39.4291	68.9763	55.8174	42.0033	77.8973	83.8347	88.9642	118.4791	87.9235	104.8900

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	178 -.062 SL= 0	178 .960 SL= 3	178 .797 SL= 3	178 -.307 SL= 3	178 -.599 SL= 3	168 -.049 SL= 0	168 -.216 SL= 3	168 -.374 SL= 3	168 .054 SL= 0	168 -.175 SL= 1
RESIDUE G/MILE		178 -.138 SL= 1	178 -.546 SL= 3	178 .731 SL= 3	178 .463 SL= 3	168 .155 SL= 1	168 -.103 SL= 0	168 .097 SL= 0	168 -.304 SL= 3	168 .081 SL= 0
EXTRACT G/KG-F			178 .795 SL= 3	178 -.214 SL= 3	178 -.618 SL= 3	168 .012 SL= 0	168 -.130 SL= 1	168 -.300 SL= 3	168 .116 SL= 0	168 -.059 SL= 0
EXTRACT %				178 -.670 SL= 3	178 -.795 SL= 3	168 -.129 SL= 1	168 -.162 SL= 1	168 -.433 SL= 3	168 .217 SL= 3	168 -.227 SL= 3
RESIDUE G/KG-F					178 .521 SL= 3	168 .387 SL= 3	168 .249 SL= 3	168 .464 SL= 3	168 -.040 SL= 0	168 .487 SL= 3
RES/EXT RATIO						168 .061 SL= 0	168 .075 SL= 0	168 .404 SL= 3	168 -.160 SL= 1	168 .141 SL= 1
100K REV PER MI							168 .897 SL= 3	168 .805 SL= 3	168 .797 SL= 3	168 .940 SL= 3
REV PER UG PART								168 .902 SL= 3	168 .866 SL= 3	168 .936 SL= 3
REV PER UG EXT									168 .638 SL= 3	168 .908 SL= 3
REV PER UG RES										168 .759 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-11. Emission and Bioactivity Correlations
CFDS Cycle - GM Vehicle Group - All Phases

```
          EXTRACT  RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER 100K REV
          G/MILE   G/MILE   G/KG-F      %     G/KG-F    RATIO  PER MI   UG PART  UG EXT   UG RES   PER KG-F

      N        73       73       73       74       73       73       71       72       72       71       71
   MEAN     .1922    .4057   1.4059  30.3232   2.9879   2.8229   4.0074    .7175   2.7917   1.0361  29.4410
STD DEV     .1410    .1174    .9819  12.3289    .8112   1.3655   1.8604    .3528   1.7873    .4941  13.1542
  RSD %   73.3505  28.9346  69.8407  40.6583  27.1487  48.3719  46.4241  49.1701  64.0237  47.6899  44.6797


                                         CORRELATION MATRIX

               RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT 100K REV  REV PER  REV PER  REV PER  100K REV
               G/MILE   G/KG-F      %     G/KG-F    RATIO   PER MI  UG PART  UG EXT   UG RES   PER KG-F

                    73       73       73       74       73       73       71       72       72       71
EXTRACT           .555    -.012     .560     .555    -.055    -.503     .165    -.092    -.280     .068
G/MILE          SL=  3   SL=  0   SL=  3   SL=  3   SL=  0   SL=  3   SL=  0   SL=  0   SL=  2   SL=  0

                             73       73       73       73       73       71       71       71       71
          RESIDUE          .216     .994     .884     .139    -.721     .224    -.265    -.515     .050
          G/MILE         SL=  1   SL=  3   SL=  3   SL=  0   SL=  3   SL=  1   SL=  1   SL=  3   SL=  0

                                      73       73       73       73       71       71       71       71
                   EXTRACT          .172    -.193     .976     .278     .113    -.324    -.133    -.367
                   G/KG-F         SL=  0   SL=  0   SL=  3   SL=  2   SL=  0   SL=  3   SL=  0   SL=  3

KEY:                                           73       73       73       71       71       71       71
                            EXTRACT          .908     .113    -.742     .182    -.282    -.535     .038
NO. OF DATA PAIRS              %           SL=  3   SL=  0   SL=  3   SL=  0   SL=  2   SL=  3   SL=  0
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL                                      73       73       71       72       72       71
                                     RESIDUE          -.242    -.911     .160    -.143    -.539     .209
                                     G/KG-F         SL=  1   SL=  3   SL=  0   SL=  0   SL=  3   SL=  1
SIGNIFICANCE LEVELS:
                                                                 73       71       71       71       71
SL = 1 FOR 0.05>ALPHA>0.01                    RES/EXT          .319     .046    -.350    -.135    -.412
SL = 2 FOR 0.01>ALPHA>0.005                    RATIO         SL=  3   SL=  0   SL=  3   SL=  0   SL=  3
SL = 3 FOR 0.005>ALPHA
                                                                          71       71       71       71
                                                       100K REV        -.140     .066     .545    -.252
                                                        PER MI       SL=  0   SL=  0   SL=  3   SL=  1

                                                                                   71       71       71
                                                                REV PER          .787     .563     .854
                                                                UG PART        SL=  3   SL=  3   SL=  3

                                                                                            72       71
                                                                         REV PER          .843     .928
                                                                         UG EXT         SL=  3   SL=  3

                                                                                                     71
                                                                                  REV PER          .619
                                                                                  UG RES         SL=  3
```

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TABLE E-12. Emission and Bioactivity Correlations
CFDS Cycle - VW Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	48	48	47	48	47	48	46	46	47	46	45
MEAN	.0759	.2540	1.0829	23.2287	3.6438	3.7813	6.1676	1.8827	9.7768	2.4250	89.6097
STD DEV	.0301	.0641	.4324	8.2275	.9312	1.4480	4.3358	1.3538	8.2242	1.6431	64.6038
RSD %	39.6685	25.2274	39.9272	35.4194	25.5555	38.2936	70.3004	71.9066	84.1201	67.7561	72.0947

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	48 .078 SL= 0	47 .994 SL= 3	48 .792 SL= 3	47 .043 SL= 0	48 -.774 SL= 3	46 -.061 SL= 0	46 -.209 SL= 0	46 -.416 SL= 3	46 -.084 SL= 0	45 -.077 SL= 0
RESIDUE G/MILE		47 .049 SL= 0	48 -.513 SL= 3	47 .980 SL= 3	48 .501 SL= 3	46 .388 SL= 3	46 .098 SL= 0	46 .235 SL= 0	46 .023 SL= 0	45 .370 SL= 2
EXTRACT G/KG-F			47 .785 SL= 3	47 .073 SL= 0	47 -.767 SL= 3	45 -.047 SL= 0	45 -.177 SL= 0	45 -.387 SL= 3	45 -.052 SL= 0	45 -.055 SL= 0
EXTRACT %				47 -.527 SL= 3	48 -.949 SL= 3	46 -.285 SL= 1	46 -.250 SL= 1	46 -.495 SL= 3	46 -.101 SL= 0	45 -.288 SL= 1
RESIDUE G/KG-F					47 .519 SL= 3	45 .414 SL= 3	45 .154 SL= 0	45 .291 SL= 1	45 .077 SL= 0	45 .401 SL= 3
RES/EXT RATIO						46 .325 SL= 1	46 .280 SL= 1	46 .542 SL= 3	46 .144 SL= 0	45 .324 SL= 1
100K REV PER MI							46 .932 SL= 3	46 .907 SL= 3	46 .915 SL= 3	45 .996 SL= 3
REV PER UG PART								46 .952 SL= 3	46 .987 SL= 3	45 .948 SL= 3
REV PER UG EXT									46 .895 SL= 3	45 .921 SL= 3
REV PER UG RES										45 .930 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-13. Emission and Bioactivity Correlations
CFDS Cycle - MB Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	22	22	22	22	22	22	20	20	20	20	20
MEAN	.0663	.3539	.5823	16.0082	2.9613	6.6285	3.2547	.7480	6.3900	.8681	26.6824
STD DEV	.0323	.0606	.3374	8.0719	.3362	3.0424	2.6235	.4778	5.8607	.5204	19.8239
RSD %	48.8104	17.1347	57.9327	50.4234	11.3539	45.8988	80.6063	63.8795	91.7161	59.9459	74.2957

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	22 -.648 SL= 3	22 .997 SL= 3	22 .990 SL= 3	22 -.296 SL= 0	22 -.907 SL= 3	20 -.191 SL= 0	20 -.212 SL= 0	20 -.395 SL= 1	20 -.111 SL= 0	20 -.120 SL= 0
RESIDUE G/MILE		22 -.665 SL= 3	22 -.745 SL= 3	22 .858 SL= 3	22 .844 SL= 3	20 .595 SL= 3	20 .481 SL= 1	20 .682 SL= 3	20 .411 SL= 1	20 .536 SL= 2
EXTRACT G/KG-F			22 .990 SL= 3	22 -.295 SL= 0	22 -.917 SL= 3	20 -.212 SL= 0	20 -.230 SL= 0	20 -.415 SL= 1	20 -.128 SL= 0	20 -.138 SL= 0
EXTRACT %				22 -.413 SL= 1	22 -.944 SL= 3	20 -.282 SL= 0	20 -.280 SL= 0	20 -.476 SL= 1	20 -.179 SL= 0	20 -.209 SL= 0
RESIDUE G/KG-F					22 .492 SL= 2	20 .590 SL= 3	20 .455 SL= 1	20 .565 SL= 3	20 .427 SL= 1	20 .576 SL= 3
RES/EXT RATIO						20 .328 SL= 0	20 .278 SL= 0	20 .515 SL= 2	20 .183 SL= 0	20 .247 SL= 0
100K REV PER MI							20 .977 SL= 3	20 .970 SL= 3	20 .964 SL= 3	20 .994 SL= 3
REV PER UG PART								20 .942 SL= 3	20 .994 SL= 3	20 .982 SL= 3
REV PER UG EXT									20 .905 SL= 3	20 .941 SL= 3
REV PER UG RES										20 .980 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-14. Emission and Bioactivity Correlations CFDS Cycle - "Other" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	37	36	37	37	36	36	33	33	33	32	33
MEAN	.1944	.2562	1.6373	45.2053	2.1958	1.7078	6.0494	1.2956	3.9242	2.4335	52.4203
STD DEV	.0721	.1225	.6053	18.3256	1.1180	1.2532	4.0479	.6990	3.6315	1.3676	38.1569
RSD %	37.1071	47.8131	36.9674	40.5386	50.9154	73.3774	66.9149	53.9501	92.5391	56.1991	72.7903

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	36 -.581 SL= 3	37 .943 SL= 3	37 .872 SL= 3	36 -.610 SL= 3	36 -.821 SL= 3	33 -.128 SL= 0	33 -.134 SL= 0	33 -.480 SL= 3	32 .423 SL= 2	33 -.174 SL= 0
RESIDUE G/MILE		36 -.553 SL= 3	36 -.890 SL= 3	36 .959 SL= 3	36 .853 SL= 3	32 .569 SL= 3	32 .308 SL= 1	32 .629 SL= 3	32 -.287 SL= 0	32 .573 SL= 3
EXTRACT G/KG-F			37 .823 SL= 3	36 -.502 SL= 3	36 -.771 SL= 3	33 -.048 SL= 0	33 -.062 SL= 0	33 -.406 SL= 2	32 .428 SL= 2	33 -.047 SL= 0
EXTRACT %				36 -.884 SL= 3	36 -.942 SL= 3	33 -.371 SL= 1	33 -.223 SL= 0	33 -.605 SL= 3	32 .443 SL= 2	33 -.405 SL= 2
RESIDUE G/KG-F					36 .866 SL= 3	32 .622 SL= 3	32 .391 SL= 1	32 .693 SL= 3	32 -.227 SL= 0	32 .664 SL= 3
RES/EXT RATIO						32 .443 SL= 2	32 .306 SL= 1	32 .731 SL= 3	32 -.312 SL= 1	32 .471 SL= 3
100K REV PER MI							33 .918 SL= 3	33 .877 SL= 3	32 .543 SL= 3	33 .987 SL= 3
REV PER UG PART								33 .829 SL= 3	32 .747 SL= 3	33 .907 SL= 3
REV PER UG EXT									32 .299 SL= 1	33 .886 SL= 3
REV PER UG RES										32 .495 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-15. Emission and Bioactivity Correlations
CFDS Cycle - "All" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	180	179	179	181	178	179	170	171	172	169	169
MEAN	.1462	.3286	1.2677	29.7437	2.9975	3.3233	4.8997	1.1461	5.3360	1.6588	49.6221
STD DEV	.1134	.1230	.7931	15.4190	.9979	2.1786	3.4156	.9498	5.8708	1.3092	46.3857
RSD %	77.5317	37.4253	62.5662	51.8394	33.2892	65.5552	69.7105	82.8740	110.0215	78.9212	93.4780

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	179 .164 SL= 1	179 .944 SL= 3	180 .770 SL= 3	178 -.201 SL= 3	179 -.631 SL= 3	170 -.004 SL= 0	170 -.243 SL= 3	170 -.396 SL= 3	169 -.038 SL= 0	169 -.170 SL= 1
RESIDUE G/MILE		178 -.003 SL= 0	179 -.394 SL= 3	178 .644 SL= 3	179 .311 SL= 3	169 .065 SL= 0	169 -.254 SL= 3	169 -.075 SL= 0	169 -.397 SL= 3	168 -.106 SL= 0
EXTRACT G/KG-F			179 .816 SL= 3	178 -.141 SL= 1	178 -.697 SL= 3	169 .063 SL= 0	169 -.128 SL= 1	169 -.332 SL= 3	168 .084 SL= 0	169 -.028 SL= 0
EXTRACT %				178 -.607 SL= 3	179 -.828 SL= 3	170 -.065 SL= 0	171 -.137 SL= 1	171 -.431 SL= 3	169 .206 SL= 3	169 -.163 SL= 1
RESIDUE G/KG-F					178 .440 SL= 3	168 .336 SL= 3	168 .193 SL= 2	168 .364 SL= 3	168 -.049 SL= 0	168 .410 SL= 3
RES/EXT RATIO						169 .049 SL= 0	169 .104 SL= 0	169 .456 SL= 3	169 -.136 SL= 1	168 .112 SL= 0
100K REV PER MI							170 .870 SL= 3	170 .775 SL= 3	169 .807 SL= 3	169 .914 SL= 3
REV PER UG PART								171 .896 SL= 3	169 .917 SL= 3	169 .949 SL= 3
REV PER UG EXT									169 .698 SL= 3	169 .870 SL= 3
REV PER UG RES										168 .837 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-16. Emission and Bioactivity Correlations
NY City Cycle - GM Vehicle - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	29	29	29	30	29	29	26	27	27	26	26
MEAN	.5422	1.4047	1.5984	27.0646	4.1800	3.0046	7.8294	.3998	1.6852	.5557	23.3432
STD DEV	.2072	.2435	.5721	8.6769	.7406	1.2276	3.6541	.1817	.9765	.2395	10.8994
RSD %	38.2187	17.3357	35.7900	32.0598	17.7167	40.8561	46.6715	45.4541	57.9484	43.0899	46.6920

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	29 -.019 SL= 0	29 .992 SL= 3	29 .925 SL= 3	29 -.169 SL= 0	29 -.913 SL= 3	26 .048 SL= 0	26 -.155 SL= 0	26 -.524 SL= 3	26 .078 SL= 0	26 -.000 SL= 0
RESIDUE G/MILE		29 -.030 SL= 0	29 -.380 SL= 1	29 .937 SL= 3	29 .283 SL= 0	26 .421 SL= 1	26 .136 SL= 0	26 .252 SL= 0	26 .019 SL= 0	26 .414 SL= 1
EXTRACT G/KG-F			29 .923 SL= 3	29 -.140 SL= 0	29 -.918 SL= 3	26 .040 SL= 0	26 -.161 SL= 0	26 -.528 SL= 3	26 .068 SL= 0	26 .006 SL= 0
EXTRACT %				29 -.492 SL= 3	29 -.965 SL= 3	26 -.080 SL= 0	27 -.127 SL= 0	27 -.542 SL= 3	26 .093 SL= 0	26 -.122 SL= 0
RESIDUE G/KG-F					29 .392 SL= 1	26 .369 SL= 1	26 .128 SL= 0	26 .286 SL= 0	26 -.015 SL= 0	26 .406 SL= 1
RES/EXT RATIO						26 -.008 SL= 0	26 .101 SL= 0	26 .532 SL= 3	26 -.148 SL= 0	26 .030 SL= 0
100K REV PER MI							26 .926 SL= 3	26 .761 SL= 3	26 .907 SL= 3	26 .991 SL= 3
REV PER UG PART								27 .867 SL= 3	26 .962 SL= 3	26 .931 SL= 3
REV PER UG EXT									26 .717 SL= 3	26 .782 SL= 3
REV PER UG RES										26 .901 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-17. Emission and Bioactivity Correlations
NY City Cycle - VW Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	16	16	16	16	16	16	14	14	16	14	14
MEAN	.1525	.3051	1.1754	32.8309	2.4021	2.4908	5.4930	1.1905	6.5462	1.9249	42.7260
STD DEV	.0731	.0656	.5037	13.0653	.5802	1.2647	3.5068	.7431	7.7884	1.5452	27.6700
RSD %	47.9534	21.5172	42.8559	39.7958	24.1538	50.7766	63.8405	62.4190	118.9744	80.2712	64.7614

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	16 -.602 SL= 2	16 .994 SL= 3	16 .957 SL= 3	16 -.677 SL= 3	16 -.862 SL= 3	14 .184 SL= 0	14 .103 SL= 0	14 -.455 SL= 0	14 .433 SL= 0	14 .109 SL= 0
RESIDUE G/MILE		16 -.619 SL= 3	16 -.784 SL= 3	16 .980 SL= 3	16 .860 SL= 3	14 .037 SL= 0	14 -.081 SL= 0	14 .554 SL= 1	14 -.409 SL= 0	14 .104 SL= 0
EXTRACT G/KG-F			16 .966 SL= 3	16 -.676 SL= 3	16 -.880 SL= 3	14 .203 SL= 0	14 .124 SL= 0	14 -.449 SL= 0	14 .458 SL= 0	14 .128 SL= 0
EXTRACT %				16 -.827 SL= 3	16 -.943 SL= 3	14 .178 SL= 0	14 .152 SL= 0	14 -.504 SL= 1	14 .518 SL= 1	14 .100 SL= 0
RESIDUE G/KG-F					16 .886 SL= 3	14 .070 SL= 0	14 -.031 SL= 0	14 .612 SL= 2	14 -.378 SL= 0	14 .143 SL= 0
RES/EXT RATIO						14 .058 SL= 0	14 .050 SL= 0	14 .685 SL= 3	14 -.335 SL= 0	14 .135 SL= 0
100K REV PER MI							14 .971 SL= 3	14 .735 SL= 3	14 .875 SL= 3	14 .996 SL= 3
REV PER UG PART								14 .724 SL= 3	14 .905 SL= 3	14 .966 SL= 3
REV PER UG EXT									14 .371 SL= 0	14 .765 SL= 3
REV PER UG RES										14 .839 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

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TABLE E-18. Emission and Bioactivity Correlations
NY City Cycle - MB Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	9	9	9	10	9	9	7	8	8	7	7
MEAN	.1464	.7663	.7030	16.5107	3.5982	5.9194	2.6667	.3106	2.1500	.3478	12.6459
STD DEV	.0554	.1239	.3084	5.6980	.5918	2.2336	1.2427	.1241	.8071	.1537	6.3959
RSD %	37.8649	16.1670	43.8675	34.5108	16.4471	37.7340	46.5998	39.9597	37.5400	44.1833	50.5768

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	9 -.252 SL= 0	9 .985 SL= 3	9 .960 SL= 3	9 .092 SL= 0	9 -.913 SL= 3	7 .490 SL= 0	7 .421 SL= 0	7 -.026 SL= 0	7 .509 SL= 0	7 .632 SL= 0
RESIDUE G/MILE		9 -.269 SL= 0	9 -.509 SL= 0	9 .870 SL= 3	9 .579 SL= 0	7 -.020 SL= 0	7 -.316 SL= 0	7 -.122 SL= 0	7 -.347 SL= 0	7 -.031 SL= 0
EXTRACT G/KG-F			9 .957 SL= 3	9 .131 SL= 0	9 -.920 SL= 3	7 .459 SL= 0	7 .406 SL= 0	7 -.053 SL= 0	7 .498 SL= 0	7 .608 SL= 0
EXTRACT %				9 -.158 SL= 0	9 -.976 SL= 3	7 .402 SL= 0	8 .550 SL= 0	8 -.045 SL= 0	7 .575 SL= 0	7 .533 SL= 0
RESIDUE G/KG-F					9 .207 SL= 0	7 .231 SL= 0	7 -.066 SL= 0	7 -.092 SL= 0	7 -.055 SL= 0	7 .292 SL= 0
RES/EXT RATIO						7 -.544 SL= 0	7 -.645 SL= 0	7 -.199 SL= 0	7 -.721 SL= 1	7 -.645 SL= 0
100K REV PER MI							7 .953 SL= 3	7 .852 SL= 2	7 .943 SL= 3	7 .983 SL= 3
REV PER UG PART								8 .806 SL= 2	7 .994 SL= 3	7 .929 SL= 3
REV PER UG EXT									7 .813 SL= 1	7 .750 SL= 1
REV PER UG RES										7 .938 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-19. Emission and Bioactivity Correlations
NY City Cycle - "Other" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	22	22	22	22	22	22	18	18	18	18	18
MEAN	.4717	.4839	1.9819	48.6066	2.1875	1.4522	6.3804	.6402	1.7444	1.2299	30.9402
STD DEV	.2148	.2212	.8472	19.6113	1.2243	1.0853	5.3240	.4508	1.2118	.8735	30.8755
RSD %	45.5508	45.7034	42.7479	40.3471	55.9672	74.7352	83.4418	70.4156	69.4675	71.0195	99.7910

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	22 -.407 SL= 1	22 .799 SL= 3	22 .914 SL= 3	22 -.434 SL= 1	22 -.903 SL= 3	18 .096 SL= 0	18 -.075 SL= 0	18 -.460 SL= 1	18 .351 SL= 0	18 .048 SL= 0
RESIDUE G/MILE		22 -.202 SL= 0	22 -.714 SL= 3	22 .944 SL= 3	22 .574 SL= 3	18 .519 SL= 1	18 .355 SL= 0	18 .568 SL= 2	18 -.037 SL= 0	18 .476 SL= 1
EXTRACT G/KG-F			22 .713 SL= 3	22 -.079 SL= 0	22 -.787 SL= 3	18 .451 SL= 1	18 .297 SL= 0	18 -.117 SL= 0	18 .554 SL= 2	18 .451 SL= 1
EXTRACT %				22 -.688 SL= 3	22 -.945 SL= 3	18 -.145 SL= 0	18 -.212 SL= 0	18 -.605 SL= 3	18 .293 SL= 0	18 -.159 SL= 0
RESIDUE G/KG-F					22 .548 SL= 3	18 .638 SL= 3	18 .515 SL= 1	18 .689 SL= 3	18 .131 SL= 0	18 .631 SL= 3
RES/EXT RATIO						18 -.009 SL= 0	18 .075 SL= 0	18 .531 SL= 1	18 -.347 SL= 0	18 .004 SL= 0
100K REV PER MI							18 .946 SL= 3	18 .790 SL= 3	18 .813 SL= 3	18 .990 SL= 3
REV PER UG PART								18 .855 SL= 3	18 .849 SL= 3	18 .964 SL= 3
REV PER UG EXT									18 .516 SL= 1	18 .804 SL= 3
REV PER UG RES										18 .820 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

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TABLE E-20. Emission and Bioactivity Correlations
NY City Cycle - "All" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	76	76	76	78	76	76	65	67	69	65	65
MEAN	.3929	.8310	1.5143	32.9703	3.1600	2.7922	6.3689	.6190	2.8817	1.0149	28.4697
STD DEV	.2458	.5103	.7446	16.9977	1.2467	1.8659	4.2334	.5257	4.2793	1.0201	23.3070
RSD %	62.5636	61.4096	49.1698	51.5545	39.4533	66.8239	66.4697	84.9349	148.4991	100.5141	81.8659

CORRELATION MATRIX :

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	76 .378 SL= 3	76 .824 SL= 3	76 .586 SL= 3	76 .050 SL= 0	76 -.588 SL= 3	65 .284 SL= 1	65 -.269 SL= 1	65 -.485 SL= 3	65 -.085 SL= 0	65 -.069 SL= 0
RESIDUE G/MILE		76 -.005 SL= 0	76 -.461 SL= 3	76 .874 SL= 3	76 .309 SL= 3	65 .359 SL= 3	65 -.388 SL= 3	65 -.225 SL= 1	65 -.457 SL= 3	65 -.135 SL= 0
EXTRACT G/KG-F			76 .794 SL= 3	76 -.184 SL= 0	76 -.779 SL= 3	65 .365 SL= 3	65 .056 SL= 0	65 -.349 SL= 3	65 .269 SL= 1	65 .248 SL= 1
EXTRACT %				76 -.688 SL= 3	76 -.844 SL= 3	65 .019 SL= 0	67 .133 SL= 0	67 -.308 SL= 2	65 .420 SL= 3	65 .089 SL= 0
RESIDUE G/KG-F					76 .505 SL= 3	65 .412 SL= 3	65 -.197 SL= 0	65 .050 SL= 0	65 -.371 SL= 3	65 .086 SL= 0
RES/EXT RATIO						65 -.179 SL= 0	65 -.186 SL= 0	65 .248 SL= 1	65 -.372 SL= 3	65 -.190 SL= 0
100K REV PER MI							65 .563 SL= 3	65 .412 SL= 3	65 .491 SL= 3	65 .807 SL= 3
REV PER UG PART								67 .794 SL= 3	65 .916 SL= 3	65 .904 SL= 3
REV PER UG EXT									65 .526 SL= 3	65 .707 SL= 3
REV PER UG RES										65 .810 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-21. Emission and Bioactivity Correlations
IDLE Cycle - GM Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	72	72	29	73	29	72	69	70	70	69	26
MEAN	.0393	.1455	2.2700	20.7310	6.4888	4.4698	.8245	.4412	2.3286	.5658	38.9337
STD DEV	.0200	.0224	.9298	7.6753	1.0045	1.8689	.4789	.2342	1.3078	.3130	17.4601
RSD %	50.9908	15.3906	40.9606	37.0236	15.4806	41.8113	58.0893	53.0813	56.1652	55.3239	44.8458

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	72 .089 SL= 0	29 .993 SL= 3	72 .940 SL= 3	29 -.247 SL= 0	72 -.812 SL= 3	69 .405 SL= 3	69 .218 SL= 1	69 -.270 SL= 1	69 .400 SL= 3	26 .351 SL= 1
RESIDUE G/MILE		29 .014 SL= 0	72 -.223 SL= 1	29 .872 SL= 3	72 .263 SL= 1	69 .274 SL= 1	69 .079 SL= 0	69 .227 SL= 1	69 .039 SL= 0	26 .432 SL= 1
EXTRACT G/KG-F			29 .947 SL= 3	29 -.199 SL= 0	29 -.870 SL= 3	26 .509 SL= 3	26 .272 SL= 0	26 -.457 SL= 2	26 .562 SL= 3	26 .406 SL= 1
EXTRACT %				29 -.488 SL= 3	72 -.921 SL= 3	69 .318 SL= 3	70 .205 SL= 1	70 -.337 SL= 3	69 .393 SL= 3	26 .203 SL= 0
RESIDUE G/KG-F					29 .469 SL= 3	26 .424 SL= 1	26 .377 SL= 1	26 .639 SL= 3	26 .169 SL= 0	26 .485 SL= 2
RES/EXT RATIO						69 -.333 SL= 3	69 -.268 SL= 1	69 .287 SL= 2	69 -.416 SL= 3	26 -.138 SL= 0
100K REV PER MI							69 .954 SL= 3	69 .729 SL= 3	69 .963 SL= 3	26 .984 SL= 3
REV PER UG PART								70 .821 SL= 3	69 .977 SL= 3	26 .969 SL= 3
REV PER UG EXT									69 .696 SL= 3	26 .575 SL= 3
REV PER UG RES										26 .938 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-22. Emission and Bioactivity Correlations
IDLE Cycle - VW Vehicle Group - All Phases

```
          EXTRACT  RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT  100K REV  REV PER  REV PER  REV PER  100K REV
          G/MILE   G/MILE   G/KG-F      %     G/KG-F    RATIO   PER MI   UG PART   UG EXT   UG RES   PER KG-F

    N          46       46       17       46       17       46       43       43       45       43       15
  MEAN      .0118    .0066   1.6534  54.9267   1.1119   1.4058    .2225   1.2073   2.4889   3.6785  44.0289
STD DEV     .0114    .0030   1.4085  21.8928    .4505   2.5217    .3061   2.0093   3.6464   5.8789  49.3165
 RSD % , 96.9161  45.4463  85.1908  39.8581  40.5216 179.3810 137.5820 166.4265 146.5085 159.8201 112.0094

                                     CORRELATION MATRIX

              , RESIDUE  EXTRACT  EXTRACT  RESIDUE  RES/EXT  100K REV  REV PER  REV PER  REV PER  100K REV
                G/MILE   G/KG-F      %     G/KG-F    RATIO   PER MI   UG PART   UG EXT   UG RES   PER KG-F

EXTRACT             46       17       46       17       46       43       43       43       43       15
G/MILE            .223     .997     .755     .115    -.353     .513     .025    -.124     .266     .411
                SL=  0   SL=  3   SL=  3   SL=  0   SL=  2   SL=  3   SL=  0   SL=  0   SL=  1   SL=  0

         RESIDUE           17       46       17       46       43       43       43       43       15
         G/MILE          .191    -.260     .977     .159     .240    -.081    -.078    -.190    -.217
                       SL=  0   SL=  1   SL=  3   SL=  0   SL=  0   SL=  0   SL=  0   SL=  0   SL=  0

                  EXTRACT           17       17       17       15       15       15       15       15
                  G/KG-F          .788     .107    -.398     .395    -.114    -.239     .114     .396
                                SL=  3   SL=  0   SL=  0   SL=  0   SL=  0   SL=  0   SL=  0   SL=  0
KEY:
                           EXTRACT           17       46       43       43       43       43       15
NO. OF DATA PAIRS             %            -.414    -.595     .412     .106    -.082     .433     .521
SAMPLE CORR. COEFF.                       SL=  1   SL=  3   SL=  3   SL=  0   SL=  0   SL=  3   SL=  1
SIGNIFICANCE LEVEL
                                   RESIDUE           17       15       15       15       15       15
                                   G/KG-F          .268    -.282    -.506    -.476    -.494    -.276
SIGNIFICANCE LEVELS:                             SL=  0   SL=  0   SL=  1   SL=  1   SL=  1   SL=  0

SL = 1 FOR 0.05>ALPHA>0.01                 RES/EXT           43       43       43       43       15
SL = 2 FOR 0.01>ALPHA>0.005                 RATIO          -.222    -.119     .012    -.204    -.300
SL = 3 FOR 0.005>ALPHA                                    SL=  0   SL=  0   SL=  0   SL=  0   SL=  0

                                                100K REV           43       43       43       15
                                                 PER MI          .702     .574     .758     .998
                                                               SL=  3   SL=  3   SL=  3   SL=  3

                                                      REV PER           43       43       15
                                                      UG PART         .974     .808     .741
                                                                    SL=  3   SL=  3   SL=  3

                                                           REV PER           43       15
                                                           UG EXT          .706     .653
                                                                         SL=  3   SL=  3

                                                                REV PER           15
                                                                UG RES          .888
                                                                              SL=  3
```

TABLE E-23. Emission and Bioactivity Correlations
IDLE Cycle - MB Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	22	22	10	22	10	22	20	20	20	20	8
MEAN	.0071	.0403	.7966	15.3691	4.0652	6.0468	.1823	.4105	2.8800	.4825	17.8519
STD DEV	.0022	.0103	.3517	4.6047	.8976	2.0176	.1125	.2807	1.8875	.3309	8.7418
RSD %	31.1607	25.6867	44.1536	29.9611	22.0812	33.3660	61.7247	68.3790	65.5392	68.5926	48.9684

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	22 .068 SL= 0	10 .951 SL= 3	22 .769 SL= 3	10 .390 SL= 0	22 -.621 SL= 3	20 -.079 SL= 0	20 -.229 SL= 0	20 -.371 SL= 0	20 -.205 SL= 0	8 .107 SL= 0
RESIDUE G/MILE		10 -.100 SL= 0	22 -.566 SL= 3	10 .649 SL= 1	22 .681 SL= 3	20 -.118 SL= 0	20 -.385 SL= 1	20 -.230 SL= 0	20 -.408 SL= 1	8 -.136 SL= 0
EXTRACT G/KG-F			10 .896 SL= 3	10 .460 SL= 0	10 -.837 SL= 3	8 .284 SL= 0	8 .064 SL= 0	8 -.041 SL= 0	8 .080 SL= 0	8 .437 SL= 0
EXTRACT %				10 .022 SL= 0	22 -.936 SL= 3	20 -.020 SL= 0	20 .104 SL= 0	20 -.141 SL= 0	20 .144 SL= 0	8 .354 SL= 0
RESIDUE G/KG-F					10 .002 SL= 0	8 .283 SL= 0	8 -.088 SL= 0	8 -.049 SL= 0	8 -.091 SL= 0	8 .369 SL= 0
RES/EXT RATIO						20 -.110 SL= 0	20 -.230 SL= 0	20 .011 SL= 0	20 -.267 SL= 0	8 -.325 SL= 0
100K REV PER MI							20 .950 SL= 3	20 .949 SL= 3	20 .943 SL= 3	8 .961 SL= 3
REV PER UG PART								20 .963 SL= 3	20 .999 SL= 3	8 .888 SL= 3
REV PER UG EXT									20 .949 SL= 3	8 .872 SL= 3
REV PER UG RES										8 .885 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-24. Emission and Bioactivity Correlations
IDLE Cycle - "Other" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	37	37	22	37	22	37	33	33	33	33	18
MEAN	.0431	.0160	3.4040	60.7690	1.2593	.9148	.2417	.6292	1.3182	1.7427	21.6140
STD DEV	.0440	.0094	3.0905	20.3677	.6961	.9380	.1547	.4378	1.1479	1.1737	12.4730
RSD %	101.9776	58.6159	90.7895	33.5166	55.2808	102.5426	63.9899	69.5827	87.0860	67.3488	57.7076

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	37 .260 SL= 0	22 .828 SL= 3	37 .837 SL= 3	22 -.171 SL= 0	37 -.584 SL= 3	33 .548 SL= 3	33 -.456 SL= 3	33 -.573 SL= 3	33 .174 SL= 0	18 .100 SL= 0
RESIDUE G/MILE		22 .050 SL= 0	37 -.058 SL= 0	22 .804 SL= 3	37 .334 SL= 1	33 .518 SL= 3	33 -.307 SL= 1	33 -.029 SL= 0	33 -.292 SL= 1	18 .113 SL= 0
EXTRACT G/KG-F			22 .758 SL= 3	22 .055 SL= 0	22 -.532 SL= 3	18 .265 SL= 0	18 -.499 SL= 1	18 -.586 SL= 3	18 .086 SL= 0	18 .304 SL= 0
EXTRACT %				22 -.486 SL= 1	37 -.880 SL= 3	33 .499 SL= 3	33 -.259 SL= 0	33 -.623 SL= 3	33 .441 SL= 3	18 .232 SL= 0
RESIDUE G/KG-F					22 .694 SL= 3	18 .198 SL= 0	18 -.167 SL= 0	18 .408 SL= 1	18 -.408 SL= 1	18 .258 SL= 0
RES/EXT RATIO						33 -.256 SL= 0	33 .150 SL= 0	33 .646 SL= 3	33 -.385 SL= 1	18 -.107 SL= 0
100K REV PER MI							33 .119 SL= 0	33 -.026 SL= 0	33 .516 SL= 3	18 .658 SL= 3
REV PER UG PART								33 .814 SL= 3	33 .675 SL= 3	18 .497 SL= 1
REV PER UG EXT									33 .277 SL= 0	18 .198 SL= 0
REV PER UG RES										18 .677 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05>ALPHA>0.01
SL = 2 FOR 0.01>ALPHA>0.005
SL = 3 FOR 0.005>ALPHA

TABLE E-25. Emission and Bioactivity Correlations
IDLE Cycle - "All" Vehicle Group - All Phases

	EXTRACT G/MILE	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
N	177	177	78	178	78	177	165	166	168	165	67
MEAN	.0289	.0693	2.2666	37.2272	3.5312	3.1263	.4732	.6733	2.2386	1.6023	32.9041
STD DEV	.0285	.0659	2.0197	24.5281	2.5950	2.7032	.4634	1.0967	2.2594	3.3034	28.0038
RSD %	98.6226	95.1333	89.1091	65.8875	73.4879	86.4659	97.9312	162.8839	100.9273	206.1694	85.1074

CORRELATION MATRIX

	RESIDUE G/MILE	EXTRACT G/KG-F	EXTRACT %	RESIDUE G/KG-F	RES/EXT RATIO	100K REV PER MI	REV PER UG PART	REV PER UG EXT	REV PER UG RES	100K REV PER KG-F
EXTRACT G/MILE	177 .300 SL= 3	78 .812 SL= 3	177 .344 SL= 3	78 .179 SL= 0	177 -.276 SL= 3	165 .483 SL= 3	165 -.129 SL= 0	165 -.218 SL= 3	165 -.040 SL= 0	67 .146 SL= 0
RESIDUE G/MILE		78 -.021 SL= 0	177 -.627 SL= 3	78 .957 SL= 3	177 .513 SL= 3	165 .661 SL= 3	165 -.207 SL= 3	165 .071 SL= 0	165 -.303 SL= 3	67 .161 SL= 0
EXTRACT G/KG-F			78 .652 SL= 3	78 -.098 SL= 0	78 -.465 SL= 3	67 .236 SL= 1	67 -.104 SL= 0	67 -.261 SL= 1	67 .046 SL= 0	67 .211 SL= 1
EXTRACT %				78 -.693 SL= 3	177 -.816 SL= 3	165 -.210 SL= 3	166 .206 SL= 3	166 -.220 SL= 3	165 .461 SL= 3	67 .177 SL= 0
RESIDUE G/KG-F					78 .440 SL= 3	67 .660 SL= 3	67 -.260 SL= 1	67 -.069 SL= 0	67 -.360 SL= 3	67 .141 SL= 0
RES/EXT RATIO						165 .101 SL= 0	165 -.221 SL= 3	165 .180 SL= 1	165 -.335 SL= 3	67 -.208 SL= 1
100K REV PER MI							165 .201 SL= 3	165 .386 SL= 3	165 .114 SL= 0	67 .689 SL= 3
REV PER UG PART								166 .842 SL= 3	165 .820 SL= 3	67 .660 SL= 3
REV PER UG EXT									165 .549 SL= 3	67 .604 SL= 3
REV PER UG RES										67 .738 SL= 3

KEY:

NO. OF DATA PAIRS
SAMPLE CORR. COEFF.
SIGNIFICANCE LEVEL

SIGNIFICANCE LEVELS:

SL = 1 FOR 0.05≥ALPHA>0.01
SL = 2 FOR 0.01≥ALPHA>0.005
SL = 3 FOR 0.005≥ALPHA